BANGKOK – PURSUIT OF NET ZERO ENERGY DESIGN

Testing the potential for a prototype high-rise residential, mixed-use building design

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Fall , December 2012

Submitted towards the fulfillment of the requirements for the Doctor of Architecture Degree

School of Architecture
University of Hawai'i at Mānoa

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We certify that we have read this Doctorate Project and that, in our opinion, it is satisfactory in scope and quality in fulfillment as a Doctorate Project for the degree of Doctor of Architecture in the School of Architecture, University of Hawai'i at Mānoa.

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Acknowledgment

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Abstract

Amid growing concerns about rising energy prices, energy independence, and the impact of climate change, buildings are considered to be the primary energy consumer in the Metropolitan area of Bangkok, Thailand. This fact underscores the importance of targeting building energy use as a key to decreasing the country's energy consumption. The building sector can significantly reduce energy use by incorporating energy-efficient strategies into the design. It can further reduce dependence on fossil fuel derived energy by increasing use of on-site and off-site renewable energy sources.

This comprehensive research project aims to pursue the Net Zero Energy (NZE) strategy that influences building performance and reduces it environmental impact. Challenged with an extreme climate of high humidity, heavy rain pour and low wind speed, the ultimate goal of the research is to design a prototypical net zero energy high-rise that reduces energy demand and satisfy internal thermal comfort. The key design approach is the integration and balance of solar energy technologies with natural ventilation strategies that will minimize energy demand and maximize renewable energy supply. The establishment of building performance criteria and energy benchmark is needed to become a baseline for prototypes that can be used for building design, energy performance target, and simulation modeling technique. Multiple research methodologies have been established and proven useful in this area of study, such as: the quantitative research methodology; whole building energy simulation; and computational fluid dynamic (CFD).

The investigation for this research focuses on the design of a prototypical residential high-rise building that is about 40,000 m^2 high. The design constraints common to metropolitan areas in Southeast Asia will be a major driving force for the design outcome, including the heat island effect and the obstructions to wind and sun. Setting up a benchmark plays an important role in pre-defining building performance. Much consideration will be given to both local and global policies, including the Bangkok Metropolitan Administration (BMA), Asian Green City Index (AGCI) and the Energy Efficiency Development Plan (EEDP). These benchmarks are established to measure the model’s proximity to the performance goals.

Doctoral Project Statement

Rapid economic growth and high density in urban settings especially in growing metropolitan areas like Bangkok, Thailand places a demand for high-rise buildings, and thereby, increasing energy consumption and carbon emission. Growing concerns about rising energy prices, energy independence, and the impact of climate change are calling for a change in the country. To address these concerns, Thailand must use energy more efficiently and reduce their environmental impact. High performance buildings must be considered as the foundation in building design strategies. Therefore, pursuing the Net-Zero or Carbon Neutral design in high-rise building will offer great opportunities for meaningful high building performance in the future. The general concept of a Net Zero Energy Building is one which produces as much energy as it uses. The building sector can significantly reduce energy use by incorporating energy-efficient strategies into the design, construction, and operation of new buildings and undertaking retrofits to improve the efficiency of existing buildings. It can further reduce dependence on fossil fuel derived energy by increasing use of on-site and off-site renewable energy sources.

Since natural ventilation uses the freely available resources of the wind and thermal energy, it will be the main focus for incorporating and energy-efficient strategies. Although these resources are free, they are difficult to control. The challenge is to provide the necessary control mechanisms to develop the required indoor air quality. To achieve this, it is necessary to understand the physics of ventilation. Building geometry is essential to any simulation of building ventilation. This paper examines the importance of building geometry into simulation of energy performance. The simulation was centered on wind-driven flows generated by wind tunnel conditions. Models of buildings are examined in an airstream and the pressure distributions around the building are measured for various orientations of the incident wind. Pressure coefficients are determined and these are used to calculate the flow through vents at different locations on the facade. The aim behind this work is to give designers rules and intuition on how air moves around and within a building; the research reveals a fascinating branch of fluid mechanics.

The proper balance between energy demand and renewable energy supply maximizes the potential for building performance and design. The key strategy to achieve such symbiosis in this thesis is to lower energy demand without sacrificing human comfort. Passive design strategy is achieved by finding a prototype that enhances both natural ventilation and solar insulation. A significant aspect in both strategies is the search for the baseline model that optimizes the use of passive energy. The investigation begins with an array of proposed building geometries that are oriented for maximum building ventilation. The thesis will also evaluate thermal conform to define how the internal environment of these geometries perform. The main focus for this thesis will be investigation of significant building components which support energy efficient design. The key measures in thermal comfort are ambient air temperature, mean radiance temperature, operative temperature, relative humidity, discomfort hours, PMV (predicted mean vote), and PPD (predicted percentage of dissatisfied) for human metabolic level.

Chapter 1
Sustainable Approach in High-Rise Buildings

1.1 Sustainable Approach in High-Rise Buildings

"How do we reduce our environmental impact while increasing our quality of life?" is one of the philosophies of ZED[1] as it will be considered to sustainable design. How do we connect community and building design to increase the quality of life? Sustainable high-rise buildings became the design goal as it has significant impact on energy use and the environment. In 2005, the Energy Information Administration (EIA) reported that commercial and residential buildings use almost 40% of the primary energy and approximately 70% of the electricity in the United States between 1980 and 2000. EIA predicted that the United States will increase demand by another 50% by 2025. Energy consumption in the commercial building sector will continue to increase until buildings can be designed to use energy efficiently and produce enough energy to balance the growing energy demand of these buildings.

The United Nations reported that half the world population is lived in urban areas in 2007. The world's urban population reached 2.9 billion in 2000 and is expected rise to 5 billion by 2030. Whereas 30 percent of the world population lived in urban areas in 1950, the proportion of urban dwellers rose to 47 percent by 2000 and is projected to increase to attain 60 percent by 2030. In contrast, the rural populations of the less developed regions are expected to grow very slowly, at just 0.2 percent per year during 2000-2030. The world rural population will remain nearly stable during 2000-2030, varying between 3.2 billion and 3.3 billion.[2] The rise of world population causes many environmental related problems, such as energy shortage, global warming, urban sprawl, air pollution, overflowing landfills, water shortage, diseases, and global conflict. These problems must be critically considered into implementation of sustainability in the future. The future urban population tends to live in tall buildings or high-rise buildings. *Tall buildings consume massive energy*[3], designers and architects of the next generation of tall buildings will incrementally aim for zero energy design.

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[1] Bill Dunster, 2008, p.2
[2] United Nation, 2001
[3] Mir M. Ali and Paul J. Armstrong, 2008

High-Rise buildings are the dominant elements in urban architecture due to their scale and purpose, and should be the focus of sustainable design.[4] A high performance tall building is one that achieves the peak efficiency of building functions while meeting the requirements of optimum performance by employing green technologies. Gordon Gill advocates performance base designs, especially in tall buildings, which must maximize the efficiency and functionality of every building element. Sustainable design strategies for tall buildings require the integration of new technology with the surrounding natural environment; in particular, the local context that can capitalize on building system performance. "The key to successful sustainable architecture is to find effective ways to integrate these systems and techniques into building design to create a synergy among the environment, the building, systems and users (the idea of Global Environmental Contextualism). The building needs to perform harmoniously with the local environmental context and take advantage of natural energy sources."[5]

	Estimated Population in Millions			*Predicted Population in 2050 in Millions*			
Area	1950	2000	2003	Low	Medium	High	Constant
Africa	221	796	851	1516	1803	2122	3279
Asia	1398	3680	3823	4274	5222	6318	7333
Latin America and the Caribbean	167	520	543	623	768	924	1032
North America	172	316	326	391	448	512	453
Oceania	13	31	32	40	46	52	58
World	2519	6071	6301	7406	8919	10633	12754

Figure 1.1: Population growth by world area
Source: United Nations, 2002

Cities are changing all over the world. In most populated countries, the large cities are getting larger. According to the United Nations (2002), the majority of the world's population will live in urban centers by 2015. It is expected that about 60 percent of the world's population will be urbanized by 2030. In 2050, over 80 percent of the world population will live in urban centers when the projected world population reaches 9 billion; at this time all major cities of the world, particularly those in Asia, Africa, and Latin America, will have enormous populations, probably ranging from 30 million to 50 million or even more. The exploding urban world population creates an increased demand for tall buildings in areas that are experiencing high density. This consequently imposes pressure on the economy in terms of construction, increased urban

[4] Mir M. Ali and Paul J. Armstrong, 2008
[5] Gordon Gill, Struct. Design Tall Spec. Build. 17, 859, 2008

services, and sensible planning. Figure1.1 presents population growth projection by major world areas, and it is evident that the highest growth will occur in Africa and Asia. Livability and quality of life depend on social factors, and must be considered in the overall urban development. For commercial buildings, the need for height is attributed to the economies of agglomeration. As countries become industrialized and service oriented, tall buildings are required to consolidate people and services in order to conduct business in urban centers. For residential buildings, urban sprawl onto agricultural land increases the cost of energy and the efficiency in the delivery of urban services; thereby, contributing to the high demand for tall buildings.

"Why should tall buildings be particularly emphasized in urban architecture?"[6] The unfortunate truth is that urban areas cannot sustain the rapid increase in population. The consequence of increasing population and growing economies in major cities around the world is a global epidemic of high density urban areas that cannot sustain its population. In the fringe of developing countries, where there are no laws to limit urban sprawl; agricultural land and a way of life are threatened. From an urban development perspective (transportation and urban services), multi-story development will save costs and energy since tall buildings can accommodate more people on less land than low-rise building on the same land. Tall building is in effect a vertical transformation of horizontal expansion. There has been evident neglect of the human factors in urban design at the expense of livability and quality of life (Mir M. Ali, 2008). The expansion of cities into the suburbs has resulted in increased travel time and energy consumption. However, tall buildings in densely built-up areas are generally recognized as efficient in terms of transportation and reducing the carbon footprint. Quality of life in an urban area is improved with tall buildings by offering the opportunities for creating open spaces in the form of plazas, parks and other community spaces, thus freeing up space at the ground level. Tall buildings show the potentials of reducing carbon footprint per capita which improve the ecological environment and economy.

Undeniably, tall buildings are integrally connected with the city because they respond to unique development conditions found within an urban environment. In many developing countries tall buildings have been designed without considering them as part of the larger urban context. Organized efforts are needed to bring together technological and socio-economic aspects of the built environment to expand our knowledge of both building typology and city

[6] Mir M. Ali and Ajla Aksamija, The 4th Architectural Conference on High Rise Buildings, 2008

form. Most of the cities in developing countries grow with very little urban planning or without any planning at all. Zoning is now fairly common; except for height limits, it has been a rarity to find an urban plan that considers the implications of tall buildings in an urban setting. However, during the last few decades, many city planning authorities have begun to employ the concentration of tall buildings as an integral feature of their plans for density and infrastructure utilization, as well as land use.

1.2 Tall Building Design Factors[7]

1.2.1 Contextual Factors

Tall buildings are influenced by the social, political, psychological, and cultural effects. Social and political changes such as growing population, development and transformation of information technology, communication systems and stability of political governments are key elements of social and political environment of a city. The contextual approach (considering users' activities, urban density, and social context, including climate, religion, history, traditions, demography and quality of life) are all factors affecting the culture of a society and the design of tall buildings. Commercial business is the largest percentage of tall buildings followed by residential function.

On the other hand, multi-use tall buildings are also very prominent, where typically commercial and residential uses are mixed. Since the use affects massing, entrance, and overall form which must be investigated in the planning phase. These require the understanding of the complex interplay of both technological and socioeconomic aspects of the built environment because the tall building is a part of the urban system; and as such depend on the adjacent buildings and street space. It must be considered within the context of the city block, the street, the pedestrian, and with regard to its users and the interior spaces they occupy.

1.2.2 Environmental Factors

Design of a tall building in an urban environment requires understanding of location, urban typology, topography, climate, and wind. These factors directly affect the quality of urban life. The local environment and its features have always been one of the most critical considerations driving the design of the built space. Tall buildings are capable of creating a

[7] Mir M. Ali and Ajla Aksamija, The 4th Architectural Conference on High Rise Buildings, 2008

significant shadow due to their size, shape, orientation, and location. Shadows produced at greater latitudes may cover an adjacent site throughout the year. On the other hand, Tall buildings can significantly block the views from adjacent buildings. The orientation of buildings must be studied to minimize interference and to maximize views. Shaded buildings have a negative impact on building functions in climates that rely on daylight. Solar gain issues play important roles in intensity of light and heat.

Wind is the most important factor in providing human comfort, thereby influences the design and structural system of tall buildings, as well as the shape and form. There are two principal external effects caused by wind. Turbulence, drafts, and gusts are created, affecting people at street level (Aynsley, 1973; Ali and Armstrong, 1995). Wind can also create problems for surrounding facilities. Some problems caused by wind that may affect buildings include difficulty of operation of entrance doors because of the adverse pressure differences; the ineffectiveness of hoods, screens and awnings; the adverse pressure effects on air-conditioning and ventilation intakes and exhausts; and pollution of cooling towers by corrosive exhausts from adjacent incinerator and furnace flues.[8]

1.2.3 Social-Economic Factors

The economics of building tall or not is very much a matter of the local condition. It can be the lowest-cost solution in a developed country in a location with other tall buildings and when the needed infrastructure and urban services are in place with adequate capacity (Mir M. Ali and Ajla Aksamija, 2008). Considering social economics, buildings may merge because such buildings accommodate both types of occupancies and their activities. Providing multi- functions such as banks, retail, and recreation facilities in the same complex creates interaction between people in the community.

Residential high rise buildings will establish a community development, which becomes the new strategy for urban planning and design. By providing an opportunity to offer facilities and economic benefits for the surrounding community, High-Rise mixed-use buildings can be located as a prime area because of transport links, amenities, and opportunities for banking and athletic facilities.

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[8] Mir M. Ali and Ajla Aksamija, The 4th Architectural Conference on High Rise Buildings, 2008

1.3 Integration Factors for Tall Buildings and Cities[9]

Tall building is a feasible solution for land scarcity and increasing population density. There are positive and negative consequences of increasing demands for urban services and infrastructure that should be addressed. The complexity of these consequences are shown where urban factors, such as economy, environment, climate, infrastructure, population, and governmental and political decisions regarding the location, size, function, structural system type, building systems, and type of envelope are demonstrated. To understand how people perceive buildings and cities, the following building characteristics are significant in constructing a skyline (Mir M. Ali and Ajla Aksamija, 2008);

- Movement: The number of persons and other objects moving in and around the building;
- Contour: The clarity of the building contour, ranging from blurred, partially obscured to free-standing;
- Shape: The complexity of the shape, ranging from simple block shape to more complex multiple shapes;
- Use intensity: The extent of building use, from limited use by a small segment of the population to daily use by large numbers of people;
- Use singularity: The uniqueness of building function, ranging from only one function to many building with shared functions;
- Significance: The extent of cultural, political, aesthetic, or historical importance of the building;
- Quality: The amount of physical maintenance, the upkeep of the structure.

Providing the appropriate design priority in High Performance building will reduce the environmental impact by using alternative design, efficient construction system, and renewable materials. There are factors to consider that suggest a listing of priorities in green design. Discussions of priorities are reflected in EBN's Priority List for Sustainable Building[10].

[9] Mir M. Ali and Ajla Aksamija, The 4th Architectural Conference on High Rise Buildings, 2008
[10] EBN Volume4, No.5, September/ October 1995

1.3.1 Save Energy—Design and build energy-efficient buildings.

The current energy use of a building is probably the single greatest environmental impact of a building, therefore designing buildings for low energy use should be our number one priority. Decisions made during the design and construction of a building will go on affecting the environmental performance of that building for decades to come, perhaps even centuries, through energy consumption. An integrated design approach can often take advantage of energy savings that become feasible when the interaction between separate building elements, such as windows, lighting, and mechanical systems, are considered.

1.3.2 Recycle Buildings, Utilize existing buildings and infrastructure instead of developing open space.

Existing buildings often contain a wealth of material and cultural resources, and contribute to a sense of place. In some cases the workmanship and quality of materials that has gone into them is almost impossible to replicate today, making the restoration all the more valuable.

1.3.3 Create Community—Design communities to reduce dependence on the automobile and to foster a sense of community.

To reduce environmental impacts, we must address transportation. Even the most energy-efficient, state-of-the-art passive solar house will carry a big environmental burden if its occupants have to get in a car each morning and commute 20 miles to work. Since the 1940s, zoning and land-use planning have, in general, been impediments to, rather than supporters of, responsible transportation patterns. Effective land-use planning can also help to foster strong communities.

1.3.4 Reduce Material Use—Optimize design to make use of smaller spaces and utilize materials efficiently.

Smaller is better relative to the environment, and no matter what the materials, using less is almost always preferable—as long as the durability or structural integrity of a building is not compromised. Reducing the surface area of a building will reduce energy consumption. Reducing waste helps both the environment and reduces cost.

1.3.5 Protect and Enhance the Site—Preserve or restore local ecosystems and biodiversity.
In fragile ecosystems or ecologically significant environments, such as old-growth forests or remnant stands of native prairie, this might be the highest priority.

1.3.6 Select Low-impact Materials—Specify low-environmental impact, resource-efficient materials.
Most—but not all—of the environmental impacts associated with building materials have already occurred by the time the materials are installed. Raw materials have been extracted from the ground or harvested from forests; pollutants have been emitted during manufacture; and energy has been invested throughout production. Some materials, such as those containing ozone-depleting HCFCs and VOCs, continue emitting pollutants during use. And some materials have significant environmental impacts associated with disposal.

1.3.7 Maximize Longevity—Design for durability and adaptability.
The longer a building lasts, the longer the period of time over which the environmental impacts from building ~~it~~ can be amortized. Designing and building a structure that will last a long time necessitates strategies for building modification to satisfy changing needs.

1.3.8 Save Water—Design buildings and landscapes that are water-efficient.
This is largely a regional issue. In some parts of the country, reducing water use is much higher on the priority list.

1.3.9 Make the Building Healthy—Provide a safe and comfortable indoor environment.
Though some people tend to separate the indoor environment from the outdoor environment, the two are integrally related, and the health of the building occupants should be ensured in any "sustainable" building. With many clients, this is the issue that first generates interest in broader concerns of environmentally sustainable building.

1.3.10 Minimize C&D Waste—Return, reuse, and recycle job-site waste and practice environmentalism in your business.
For more and more materials, sorting and recycling job-site waste is paying off economically, and it can certainly generate a good public image.

1.3.11 Green Up Your Business—Minimize the environmental impact of your own business practices, and spread the word.

In addition to creating buildings with low environmental impact, you should practice environmentalism in your own business, thus serving as a model for other design or construction firms.

This listing of EBN provides the significant outline of sustainable design purpose which is relevant to both local and global impact. High-Rise buildings play an important role in reducing the impact on environment and increasing the quality of life in the high density urban scale. It is necessary to reduce energy consumption after understanding the local and global impact to the environment. First, analyze how much energy is consumed in order to be able to estimate the potential savings. Secondly, it is essential to reduce the energy consumption by using energy in the most efficient way. Finally, the remaining needed energy should be produced by means of renewable energy sources.

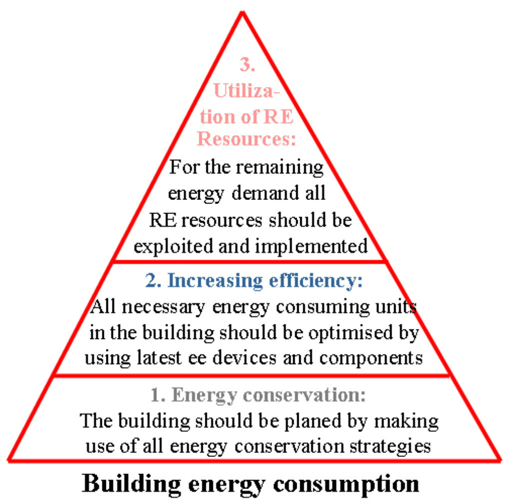

Figure1.2: Energy triangle for low energy building design[11]

High-Rise buildings in the metropolitan area are rapidly increasing in the future. High building performance and respect for local resources should be considered. Although High-Rise building is just one component of urban typology, it should be the driving force for future perspectives on sustainable environmental goals. It should be taken into consideration from the

[11] Matthias Haase and Alex Amato, PLEA 2006

beginning to study soil capacity and quality, water and waste system, and whole infrastructure in the metropolitan area to enhance the benefit of local sources, both of natural and man-made. In order to maximize building performance, we need to understand how to integrate building design with the advantages of microclimate and access to public transportation. Designing High-Rise building should correspond to *Localization* (William Lim) which considers local benchmark and serve a better quality for people's life. Only then will we be able to design for increased building performance that is site appropriate.

Flexible and adaptive designs of buildings play an important role in the sustainable high-rise building design; not merely self-efficiency of the building or the life cycle of the building, but also includes occupancies that use the buildings. This would support and promote the new living style and maintain the quality of life in the community. Good High-Rise design will reflect and respond to metropolitan policy, educate the user, conserve energy, preserve natural resources, maximize infrastructure services, and reduce negative environmental impacts. "Once designers and building professionals understand the value of the qualitative elements of sustainable design, they can begin to embrace use of sustainability to add economic value to any building project, regardless of its parameters."[12] The result is policy changing by adopting the sustainable aspect which creates more economic value. Builders take into account ~~on~~ local resources and environmental impacts in regards to reducing carbon footprint, carbon emission, and productivity of energy, which will save cost in the long run. Nevertheless, the major significance of high performance buildings design in any parameters will respond to human satisfaction, which is interrelated to the environment and economy. In achieving the ultimate goal for high performance, human comfort level, productivity of building, and sense of community are the main keys of residential building.

[12] Gordon Gill, Struct. Design Tall Spec. Build. 17, 866, 2008

Chapter 2

Urban Heat Islands (UHIs)

2.1 Urban Heat Island Basics

An urban heat island (UHI) is a metropolitan area which is significantly warmer than its surrounding rural areas. The phenomenon was first investigated and described by Luke Howard in the 1810s. Many urban and suburban areas experience elevated temperatures compared to their outlying rural surroundings; this difference in temperature is what constitutes an urban heat island. The annual mean air temperature of a city with one million or more people can be 1.8 to 5.4°F (1 to 3°C) warmer than its surroundings, and on a clear, calm night, this temperature difference can be as much as 22°F (12°C) (Eva Wong, EPA). During the summer, urban heat islands can affect a community's environment and quality of life. Most impacts are negative: increased energy consumption, elevated emissions of air pollutants and greenhouse gases, compromised human health, and impaired water quality.

Feature	Surface UHI	Atmospheric UHI
Temporal Development	• Present at all times of the day and night • Most intense during the day and in the summer	• May be small or non-existent during the day • Most intense at night or predawn and in the winter
Peak Intensity (Most intense UHI conditions)	• More spatial and temporal variation: • Day: 18 to 27°F (10 to 15°C) • Night: 9 to 18°F (5 to 10°C)	• Less variation: • Day: -1.8 to 5.4°F (-1 to 3°C) • Night: 12.6 to 21.6°F (7 to 12°C)
Typical Identification Method	• Indirect measurement: • Remote sensing	• Direct measurement: • Fixed weather stations • Mobile traverses
Typical Depiction	• Thermal image	• Isotherm map • Temperature graph

Table 2.1: Basic Characteristics of Surface and Atmospheric Urban Heat Islands (UHIs)
Source: Reducing Urban Heat Islands: Compendium of Strategies, EPA

Urban heat islands refer to the elevated temperatures in developed areas compared to more rural surroundings. Urban heat islands are caused by development and the changes in radiated and thermal properties of urban infrastructure as well as the impacts buildings can have on the local microclimate, especially in tall buildings which can slow the rate at which cities cool off at night. Heat islands are influenced by a city's geographic location and by local weather patterns, and their intensity changes on a daily and seasonal basis. The warming that results from urban heat islands over small areas, such as cities, is an example of local climate change, which is fundamentally different from global climate changes in that their effects are limited to the local scale and decrease with distance from their source. Global climate changes, such as those caused by increases in the sun's intensity or greenhouse gas concentrations, are not locally or regionally confined. The impacts from urban heat islands and global climate change or global warming are often similar. For example, some communities may experience longer growing seasons due to either or both phenomena. Urban heat islands and global climate change can both also increase energy demand, particularly summertime air conditioning demand, and associated air pollution and greenhouse gas emissions, depending on the electric system power fuel mix (Eva Wong, EPA).

In rural areas, vegetation and open land typically dominate the landscape. Trees and vegetation provide shade, which helps lower surface temperatures. They also help reduce air temperatures through a process called evapotranspiration[1], in which plants release water to the surrounding air, dissipating ambient heat. In contrast, urban areas are characterized by dry, impervious surfaces, such as conventional roofs, sidewalks, roads, and parking lots. Growth of metropolitan areas meant changes in natural vegetation with paved and covered surfaces of buildings. The huge changes in ground cover resulted in less shade and moisture to keep urban areas cool. Built up areas evaporate less water (see Figure 2.1), which contributes to elevated surface and air temperatures.

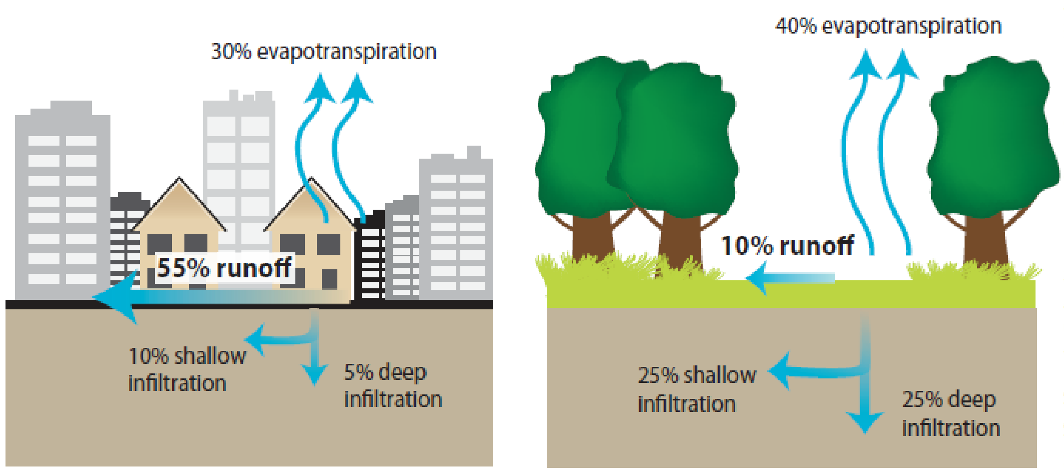

Figure 2.1: Impervious Surfaces and Reduced Evapotranspiration
Source: Reducing Urban Heat Islands: Compendium of Strategies, EPA

[1] EPA Published, Eva Wong, page 7

Urban geometry, which refers to the dimensions and spacing of buildings within a city, influences urban heat island development at night. The urban geometry also influences wind flow, energy absorption, and a given surface's ability to emit long-wave radiation back to space. In developed areas, surfaces and structures are often, at least partially, obstructed by objects (such as neighboring buildings) and become large thermal masses that cannot release their heat very readily because of these obstructions. At night, the air above urban centers is typically warmer than air over rural areas. Nighttime atmospheric heat islands can have serious health implications for urban residents during heat waves.

Factors Communities are Focusing On
• Reduced vegetation in urban regions: Reduces the natural cooling effect from shade and evapotranspiration. • Properties of urban materials: Contribute to absorption of solar energy, causing surfaces, and the air above them, to be warmer in urban areas than those in rural surroundings.
Future Factors to Consider
• Urban geometry: The height and spacing of buildings affects the amount of radiation received and emitted by urban infrastructure. • Anthropogenic heat emissions: Contribute additional warmth to the air.
Additional Factors
• Weather: Certain conditions, such as clear skies and calm winds, can foster urban heat island formation. • Geographic location: Proximity to large water bodies and mountainous terrain can influence local wind patterns and urban heat island formation.

Table 2.2: Factors that Create Urban Heat Islands
Source: Reducing Urban Heat Islands: Compendium of Strategies, EPA

2.1.1 The Urban Surface Energy Budget[2]

An energy budget provides an equation that quantifies the balance of incoming and outgoing energy flows, or fluxes (see Figure 2.2). The surface energy budgets of urban areas and their more rural surroundings will differ because of differences in land cover, surface characteristics, and level of human activity. Such differences can affect the generation and

[2] Reducing Urban Heat Islands: Compendium of Strategies, EPA

transfer of heat, which can lead to different surface and air temperatures in urban versus rural areas. Various elements of the budget include:

- Short-wave radiation is ultraviolet, visible light and near-infrared radiation from the sun that reaches the Earth (see Figure 2.2). This energy is a key driver of urban heat islands. Urban surfaces, compared to vegetation and other natural ground cover, reflect less radiation back to the atmosphere. They instead absorb and store more of it, which raises the area's temperature.
- Thermal storage increases in cities in part due to the lower solar reflectance of urban surfaces, but it is also influenced by the thermal properties of construction materials and urban geometry. Urban geometry can cause some short-wave radiation—particularly within an urban canyon—to be reflected on nearby surfaces, such as building walls, where it is absorbed rather than escaping into the atmosphere.

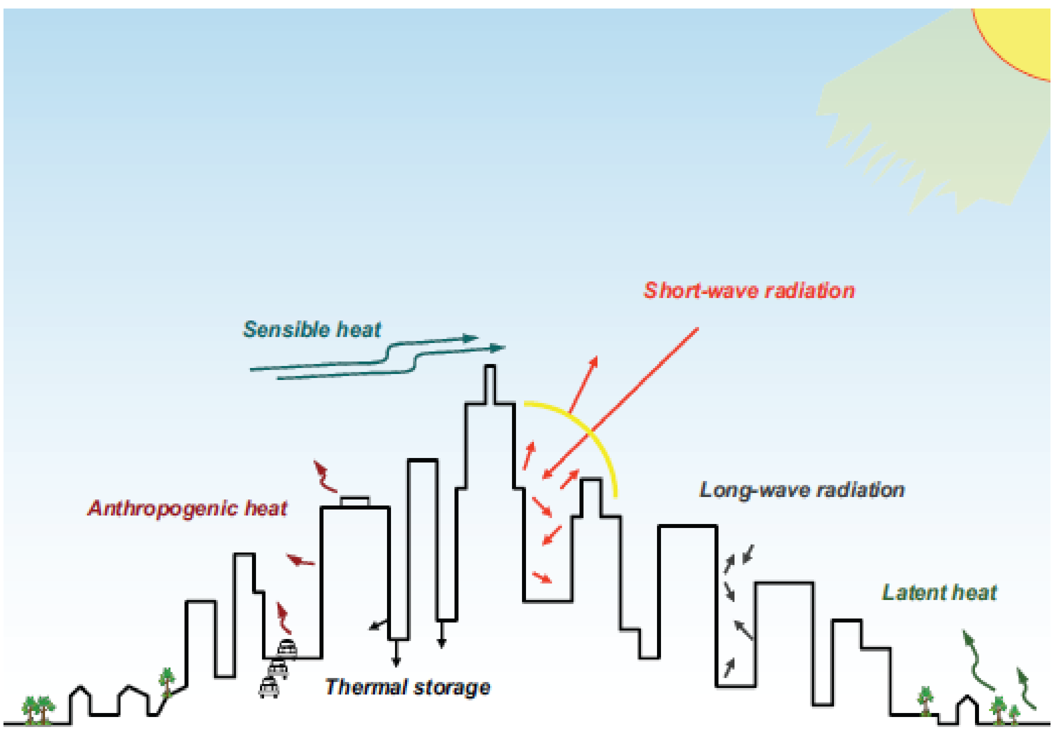

Figure 2.2: Urban Surface Energy Budget
Source: Reducing Urban Heat Islands: Compendium of Strategies, EPA

- Similarly, urban geometry can impede the release of long-wave, or infrared, radiation into the atmosphere. When buildings or other objects absorb incoming short-wave radiation, they can re-radiate that energy as long-wave energy, or heat. However, at night, due to the dense infrastructure in some developed areas that have low sky view factors, urban areas cannot easily release long-wave radiation to the cooler, open sky, and this trapped heat contributes to the urban heat island.
- Evapotranspiration describes the transfer of latent heat, what we feel as humidity, from the Earth's surface to the air via evaporating water. Urban areas tend to have less evapotranspiration relative to natural landscapes, because cities retain little moisture. This reduced moisture in built up areas leads to dry, impervious urban infrastructure reaching very high surface temperatures, which contribute to higher air temperatures.
- Convection describes the transfer of sensible heat, what we feel as temperature, between the surface and air when there is a difference in temperature between them. High urban surface temperatures warm the air above, which then circulates upwards via convection.
- Anthropogenic heat refers to the heat generated by cars, air conditioners, industrial facilities, and a variety of other manmade sources, which contributes to the urban energy budget, particularly in the winter.

2.2 Urban Heat Islands in Bangkok, Thailand

The population of Bangkok, Thailand was about 7 million by registered record or 10 million of daytime population according to the Bureau of Registration Department, 2004. Bangkok's rapid rise in population, capital investment, factories and employees caused the increasing of infrastructure networks, real estate developments, and land value. The result of expansion of the city led to several environmental problems such as air pollution, water pollution, land subsidence, as well as the effect of urban heat island such as temperature rise, high energy consumption, etc.

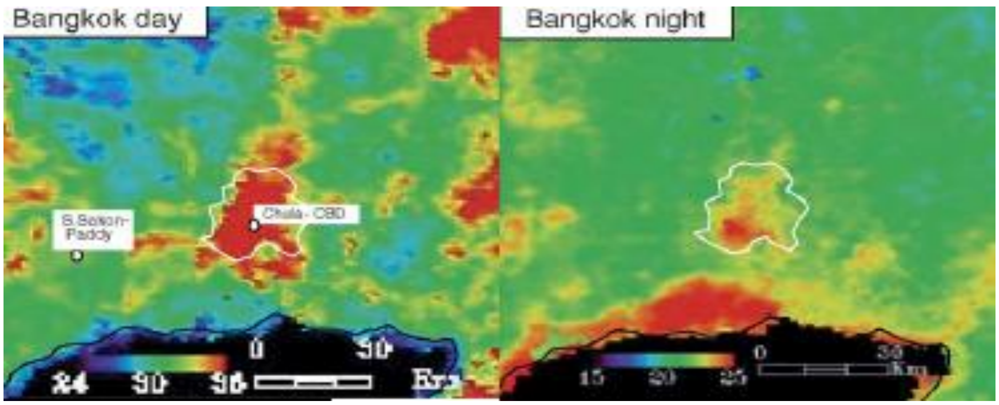

Figure 2.3: The diurnal variations of UHIs in Bangkok city [3]

The Asian Institute of Technology, National Research Council of Thailand (NRCT) by Pathathai Tonsuwonnont, conducted research in 2004. For 1 year of observation, it is evident that the heat island phenomena occur throughout the year, especially during the night time. The UHI intensity ranges: 4-5°C in cool season; 2-3°C in hot season; and 1.5-2.5°C in wet season. The heat island intensities observed at Bangkok is similar to the studies done in Mexico City where the average nocturnal UHIs reached the maximum of 5°C at about sunrise in the middle of cool season and is less intense in the wet season. The maximum intensity occurred between 7 to 9 am before sunrise. Similarly, in Bangkok the maximum intensity was observed between 6 to 7 am before sunrise. This high intensity may also be to the sensible heat during the rush hour in morning traffic. In addition, the high intensity could be a result of similar climate conditions since both cities are considered to be tropical cities. In other tropical cities like Singapore, the urban and non-urban difference of 4.01°C was observed using mobile traverse methods

[3] International Journal of Applied Earth Observation and Geoinformation, 2006

between 2-4 a.m. in 2002. Thus, due to the same climate condition (tropical) the heat island intensity is very close to each other.

2.2.1 The factors influencing the UHI magnitude[4]

2.2.1.1 Weather

To study the effect of weather condition on the heat island formation; the rainfall, wind speed and cloudiness data were obtained from Meteorological Department[5] in several locations inside and outside Bangkok.

2.2.1.2 Winds

The investigation of wind and cloud cover is presented in this section. The UHI intensity, wind speed, and cloudiness on the day with the maximal intensity (29thDecember) are shown in Figure 2.4. The wind speeds during the night time from 7 p.m. - 6 a.m. are zero while the intensities reach the highest value of 6°C. During the day time, when the wind speeds increase to around 6-8 km/hr, the magnitudes of UHI decrease to -2 to -3°C. Thus, the greater the wind speeds, the lower the UHIs develop. This presents that very calm and windless condition can lead to the largest magnitude of heat island. On the other hand, a large increase in wind speed in urban area is associated with the development of UHI. A strong heat circulation may be considered to be the cause of the rising wind speed in urban area (Robert et al, 1986).

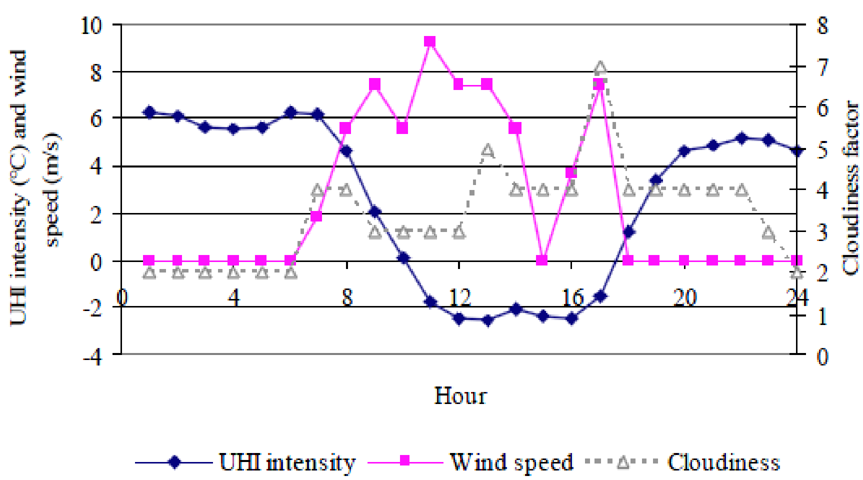

Figure 2.4: The UHI intensity, wind speed, and cloudiness on 29th, December, 2004
Source: Asian Institute of Technology, National Research Council of Thailand (NRCT), Pathathai Tonsuwonnont

[4] Pathathai Tonsuwonnont, NRCT, 2006
[5] NRCT, 2006

2.2.1.3 Clouds

The cloudiness factor from Meteorological Department is set on a 1 to 10 scale (from low-level to high-level clouds). Similar to wind speed, the UHI magnitude is inversely proportional to the cloud cover. The high-level cloud amount is found during the day time leading to the lower UHI intensity while little or no cloud is found during the nighttime causing the larger UHI intensity. However, the higher cloud amount can cause high intensity. It is explained that clouds reflect solar radiation which results in surface cooling as can be seen during the day time.

However, clouds obstruct the long wave radiation loss from the surface leading to the higher surface temperature which will results in the higher air temperature afterward; although, this depends on the cloud type.

2.2.1.4 Precipitation

Figure 2.5 shows the effect of rain on the UHI intensity. It is observed that the UHI intensity varies with precipitation. The increase of the precipitation, which has the largest value in August at 230 mm, causes the gradual decline of the UHI intensity to the lowest intensity of 2°C. Later, as the amount of rain decreases to minimum in December (0 mm), the magnitudes of heat island reach their maximum (5°C) in December. Thus, the precipitation can be considered as one of the most significant factors governing UHI development, especially in rainy season (from May to October).

On the other hand, the UHI may create precipitation in urban area. The rising warm air in urban area helps to create the clouds which results in more rainfall in urban areas and areas in downwind cities

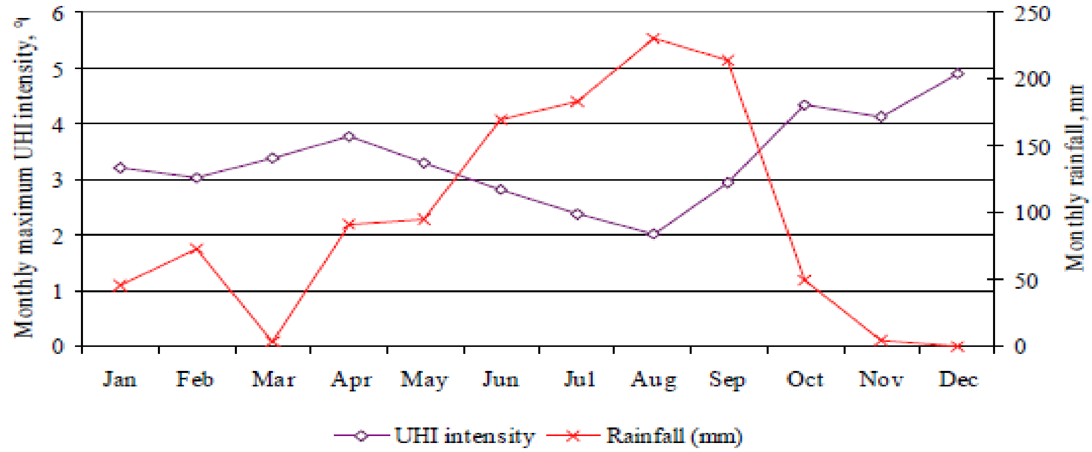

Figure 2.5: Monthly maximum UHI intensity between DD (urban) and AIT (non-urban) station and monthly rainfall (mm) in Bangkok metropolis station in 2004.
Source: Asian Institute of Technology, National Research Council of Thailand (NRCT), Pathathai Tonsuwonnont

According to the studies, the elevated temperatures from urban heat islands can affect a community's environment and quality of life. While some heat island impacts seem to be positive, such as lengthening the plant-growing season, most impacts are negative, including the increasing in energy demand for cooling and added pressure to the electricity grid in insufficiency behavior. The higher temperature will increase energy demand, which causes higher level of air pollutants and greenhouse gases such as sulfur dioxide, nitrogen oxides, particulate matter, carbon monoxide, and carbon dioxide creating the global climate change. Bangkok's air pollutions is above performance compared to other Asian metropolitan cities see figure 6.2 and 6.3 in Chapter 6.

Increased daytime surface temperatures, reduced nighttime cooling, and higher air pollution levels associated with urban heat islands can affect human health by contributing to general discomfort, respiratory difficulties, heat cramps and exhaustion, non-fatal heat stroke, and heat-related mortality. Moreover, Surface urban heat islands degrade water quality, mainly by thermal pollution. Pavement and rooftop surfaces will reach temperatures 50 to 90°F (27 to 50°C) which is higher than air temperatures transferring this excess heat to Storm water (Eva Wong, EPA).

Nevertheless, this study will navigate the urban heat situation, which ties into the design framework in the research. The study plays an important role in heat-related environmental and health issues. The research also contributes to the development of heat island reduction strategies on the architectural level including landscaping, vegetation, green roofs, and cool roofs. This thesis sets out a framework for built environment professionals and policymakers involved in planning, design, and creating sustainable communities and cities in the Bangkok Metropolitan.

Chapter 3

Zero Energy Approach in High-Rise buildings

3.1 Zero Energy Philosophy

A net zero-energy building (ZEB)[1] is a residential or commercial building with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied by renewable technologies. The zero energy goal defined affects the choices designers make to achieve this goal and whether they can claim success. The ZEB definition can emphasize demand-side or supply strategies and whether fuel switching and conversion accounting are appropriate to meet a ZEB goal.

Conceptually, a Net Zero Energy building (NZEB) produces as much as or more energy than it uses annually and exports excess renewable energy generation to the utility (electricity grid, district hot water system, or other central energy distribution system) to offset the energy used (Shanti Pless and Paul Torcellini, 2006). For NZEBs, a utility connection is allowed for energy balances. There are four commonly used accounting methods —net-zero site energy, net-zero source energy, net-zero energy costs, and net-zero energy emissions. These definitions are applied to a set of low-energy buildings for which extensive energy data are available. It also looks at sample utility rate structures and their impact on the zero energy scenarios. This classification system begins ranking energy supply options in the NZEB context. As designers and owners look to design NZEBs, a discussion of which classification to achieve would be helpful in setting goals.

From an architectural perspective, the building design as form and envelope are necessary considerations for net-zero energy, high-performance green buildings. The overall form of the structure, the climate considerations, and its location and orientation to the sun in relation to the immediate environs (including other structures) will all affect the efficiency and effectiveness of the building. Locating a building with convenient access to mass transit or to other efficient modes of transportation may also significantly reduce the indirect energy use over the life of the building.

[1] National Renewable Energy Laboratory, 2006

3.2 Net Zero Energy Building (NZEB)

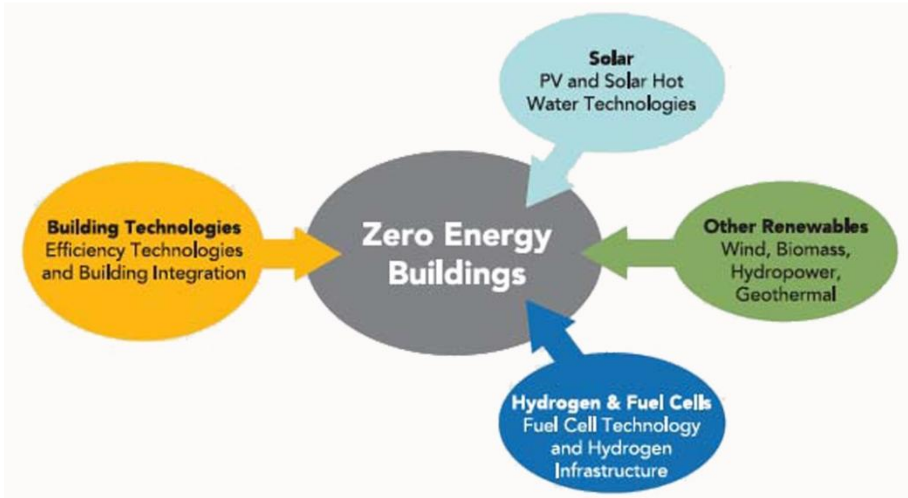

Figure3.1: Diagram for Zero Energy building Technologies and strategies frame work
Source: Federal R&D Agenda for Net Zero Energy, High Performance Green Building Report, 2008

To achieve a building with net zero energy consumption there are two classifications that generate the energy such "on-site ZEB" for building that use renewable energy from on-site sources and "off-site ZEB" for buildings that use renewable energy from sources outside the boundaries of the building site. On-site ZEB either use renewable energy sources available within the building's footprint or use renewable energy sources available at site, for example use PV, solar hot water, low-impact hydro, and wind located on-site, but not on the building. Off-site ZEB either use renewable energy sources available off site to generate energy on site or purchase off-site renewable energy sources.

A zero energy building can be defined in several ways, depending on the boundary and the metric. Different definitions may be appropriate, depending on the project goals and the values of the design team and building owner. Torcellini et al. (2009) have developed four well-documented definitions of Zero-Energy Buildings (ZEB) including:

- Net Zero Site Energy: A site ZEB produces at least as much energy as it uses in a year, when accounted for at the site.
- Net Zero Source Energy: A source ZEB produces at least as much energy as it uses in a year, when accounted for at the source. Source energy refers to the primary energy used to generate and deliver the energy to the site. To calculate a building's total source

energy, imported and exported energy is multiplied by the appropriate site-to-source conversion multipliers.

- Net Zero Energy Costs: In a cost ZEB, the amount of money the utility pays the building owner for the energy the building exports to the grid is at least equal to the amount the owner pays the utility for the energy services and energy used over the year.
- Net Zero Energy Emissions: A net-zero emissions building produces at least as much emissions-free renewable energy as it uses from emissions-producing energy sources.

To understand the NZEB characteristics above and the integrated approach I will study the *pros and cons*[2] in each definition as follows;

Site ZEB:

- Pros; It is easy to implement and verify through on-site measurements. Site ZEB is a conservative approach to achieving ZEB. There is no external effect on performance, and success can be tracked over time. It is easy for the building community to understand and communicate. This type of ZEB also encourages energy-efficient building designs.
- Cons; Site ZEB requires more PV export to offset natural gas. It does not consider all utility costs (can have a low load factor). Fuels types are also not able to be equated. Moreover, it does not account for non-energy differences between fuel types (supply availability, pollution).

Source ZEB:

- Pros; Source ZEB is able to associate energy value of fuel types used at the site and also provide better model for impact on national energy system. It is an easier ZEB to reach.
- Cons; However, source ZEB does not account for non-energy differences between fuel types (supply availability, -pollution). Source calculations too broad (do not account for regional or daily variations in electricity generation heat rates). Source energy uses accounting and fuel switching, which can have a larger impact than efficiency technologies. It also does not consider all energy costs (can have a low load factor).

Cost ZEB:

- Pros; Cost ZEB is easy to implement and measure. Market forces result in a good balance between fuel types. It allows for demand-responsive control and are able to be verified from utility bills.

[2] National Renewable Energy Laboratory, p.11

- Cons; Cost ZEB may not reflect impact to national grid for demand, as extra PV generation can be more valuable for reducing demand with on-site storage than exporting to the grid. It requires net-metering agreements such that exported electricity can offset energy and non-energy charges. Also, in Cost ZEB, the highly volatile energy rates make for difficult tracking over time.

Emission ZEB:

- Pros; It is better model for green power. It accounts for non-energy differences between fuel types (pollution, greenhouse gases). It would be easier ZEB to reach.

The concept of NZEBs becomes technically and economically feasible; extending its boundary to groups of buildings, campuses, communities, towns, bases, or cities becomes possible. An alternative to single NZEBs is zero-energy campuses, neighborhoods, or communities. Extending the net-zero energy boundaries beyond a single building addresses the emergence of communities, neighborhoods, and campuses that generate renewable energy for a certain group of buildings; however, the energy does not necessarily connect directly to a specific building's utility meter. This would be considered a community-based renewable energy system that would be connected to the grid or to a district heating or cooling system.

3.3 Net Zero Energy and High-Rise Mixed Use

Sustainable architecture is environmentally conscious, energy-saving, and utilizes responsive and renewable materials and systems (Newman, 2001). Ecological and environmental concerns have expanded beyond the issue of the consumption of non-renewable energy sources. Sustainability essentially aims for ecological balance. "Tall buildings consume massive energy, designers of the next generation of tall buildings will incrementally aim for zero energy design"[3] Before considering the zero energy design techniques, we need to understand the significant of high performance tall buildings. It will be a key factor into the ultimate goal of productivity and performance with concrete foundation and design for energy performance. High Performance tall buildings create environmental awareness to both the urban environment and the context in which a tall building is placed as well as its interior environment. The issues of outdoor microclimate and indoor air quality as well as the potential toxicity of materials and chemicals used in building components, systems, and furnishings are also known to the building

[3] Mir M. Ali and Paul J. Armstrong, CTBUH 8th World Congress 2008

users. Better tall buildings performance maximizes the positive impact of a building on the environment and on the users. "The fact is that the skyscraper can never be a truly green building, certainly not in totality"[4] As Tall buildings consume so much energy to be built and circulate energy demand vertically, tall buildings performance needs to be justified to conserve resources and preserve balance between ecology and human demand.

The vision of Net Zero Energy buildings (NZEBs) is undeniable. These highly energy-efficient buildings will use, over the course of a year, renewable technology to produce as much energy as they consume from the grid. Building owners and tenants stand to realize attractive returns on their NZEB investments while reducing carbon footprints. Especially since tall buildings are the highest energy-consuming and carbon-emitting sector, with NZEBs, our nation can gain a network of clean domestic energy assets. Regarding to building design professional societies also have recognized the vision of net zero energy buildings (NREL, 2006).

- ASHRAE Vision 2020 report (ASHRAE 2008) sets out requirements for developing the tools by 2020 to enable commercially viable net zero energy buildings by 2030. ASHRAE's recent conference on net zero energy buildings featured more than 25 posters (ASHRAE 2009) of NZEBs, some operating close to or at net zero and others in various stages of design or construction.
- The AIA 2030 Challenge (AIA 2009) calls for incrementally reducing energy use, starting with a 50% reduction over existing buildings' energy use and increasing savings up to 2030, when new buildings will be carbon neutral. Architecture firms, large and small, are beginning to make this voluntary commitment to adopt energy-saving targets in building design and implement steps to reach the carbon-neutral goal.

"Policymakers also are embracing net-zero energy buildings as a key strategy for meeting energy and carbon goals. The California Public Utilities Commission, for example, has an energy action plan to achieve net zero energy for all new residential construction by 2020 and net zero for all new commercial construction by 2030. This action plan will provide

[4] Ken Yeang, Design Tall Spec. Build. 16, 411–427 (2007)

direction for future development of California's Title 24 building energy codes, as well as incentives for net zero buildings."[5] This case study will set up the significant approach and framework for sustainable design. The ultimate goal is to be able to set up the prototype and become an example for better building performance. With high amount of social-economic prospects, Asian countries show higher population density due to rapid economic development and urbanization in the past two decades. High-rise residential buildings appear as a major demand within high density land, which tends to stimulate condominium markets to become demanding (see chapter 5). The new massive market demand requires for quality living styles and environment. "*Almost in all the major cities in Asian countries, residential buildings are characterized with high-rise and high density. Under this circumstance, achieving comfortable and healthy indoor environment with minimized energy consumption becomes a very challenging engineering and societal issue*"[6]. This issue requires homebuyers, estate developers, and to consider green building, eco-architecture, sustainable buildings, and Zero Energy solution as future design approach within limited sources.

Understanding the Net Zero Energy system in site, source, and emission classification will provide benefit to my investigation on carbon neutral design guideline and baseline. By reducing the environmental impact and carbon footprint from the building perspective is not enough. We also need to consider on-site and off-site sources. I would like to focus on the Net Zero Site Energy and Net Zero Source Energy [7] which is feasible to the selected context so that I will be able to gain a fundamental understanding in relation to NZEB and high rise buildings. The residential mixed use type provides the dynamic of programs, users, and the need for sharing resources. There is a sense of community and social space in one particular building.

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[5] Drury Crawley, NREL, 2009
[6] Jianlei Niu, Energy and Buildings 36 (2004) 1259–1263
[7] Torcellini et al., 2009

3.4 Net Zero Energy in Bangkok, Thailand

The Bangkok Metropolis is located at 13°44′ N and 100°34′ E. Bangkok has a tropical wet and dry climate under the Köppen climate classification system. Average temperatures in the city are about 2 °C higher than the ones shown for the Don Mueang Airport during the 1960-1990. The highest recorded maximum temperature is 40.8 °C (105.4 °F) in May 1983 and the lowest recorded minimum temperature is 9.9 °C (49.8 °F) in January 1955. Bangkok is the capital city of Thailand and is considered to be the heart of the country. It is the center of industries, manufacture, economy, commerce, and construction. The population was about 7 million by registered record or 10 million of daytime population from the Bureau of Registration Department, 2004. This rapid rise in population, capital investment, factories and employees in Bangkok city have caused the community numbers to increase, leading to the development of road networks, real estate developments, land value and advanced technologies which has resulted in expansion of the city to the surrounding areas. The rapid urbanization has led to several environmental problems such as air pollution, water pollution, land subsidence as well as the effect of urban heat island such as temperature rise, high energy consumption, etc.[8]

In Thailand, the green building perspective will need time to be adapted into both professional and academics participation. “The green building design process should be done by considering several factors such as location, climate and geography, as well as the strengths and weaknesses of the surrounding environment which are different depending on each location."[9] Assistant Professor Dr. Atch Sreshthaputra, a board member of the Thai Green Building Institute, stated that there was still resistance to green building in Thailand and local standards for green building construction materials are unreliable. Almost all green projects require overseas consultants and import of foreign products. Designing to reduce energy use and increase comfort is not universal, rather it is location-specific."In fact, environment-friendly construction doesn't require a huge investment but understanding, observation as well as creativity and imagination are necessary. New technology is costly and discourages to many who aspire to have green houses or offices, but with the suitable designs for Thailand, the specification result in a cost that's only 10% higher than traditional construction to build a house," Dr. Atch asserts. He also suggested that Thailand should have its own green building assessment standard. This

[8] Tonsuwonnont, page 1
[9] Asst Prof Dr Atch Sreshthaputra, Bangkok Post Newspaper, 6/09/2010

would promote the use of environment-friendly materials that are locally produced, as well as generate employment of local engineers and architects. He said that international standards such as LEED (Leadership in Energy & Environmental Design) were suitable for commercial buildings in the city but not necessarily as guidelines for all forms of green design and architecture. For any green building, energy conservation is not the only criterion.

Nevertheless, Bangkok has a high energy consumption and urban heat island effect, which diminishes the community's environment and quality of life, and can cause critical environmental damage in the future. A high performance building design approach should be immediately considered. High density of high-rise buildings in Bangkok downtown produced higher temperature and air pollutions throughout the metropolitan area, thus requiring more energy for air conditioning and refrigeration. The Ministry of Energy Thailand has established a 20-year Energy Efficiency Development Plan (EEDP) aimed to reduce energy intensity by 25% in 2030. There are multiple references and models in zero energy design solution throughout the world. Promoting and establishing a higher energy performance building design standard for Bangkok Thailand is a matter of push and implementation by policy makers and designers.

Chapter 4

Sustainable and Energy approach Thailand and Bangkok

4.1 Overview climate in Thailand

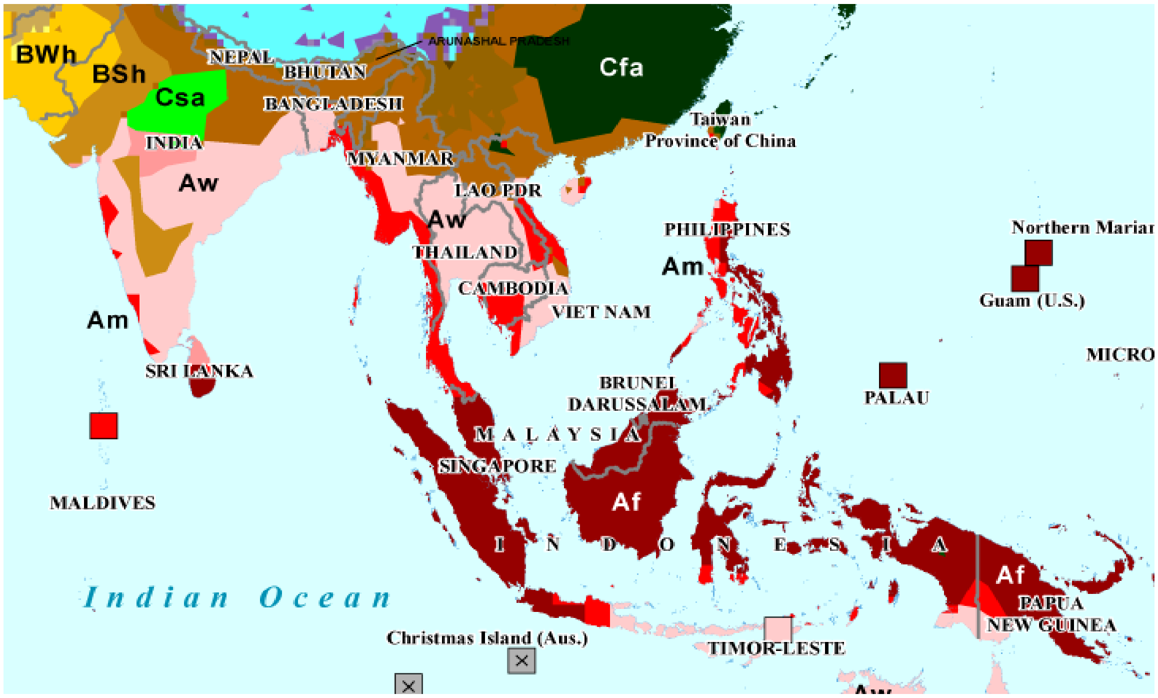

Figure 4.1: Thailand climate classification as Aw (Equatorial and Winter dry)
Source: Koppen-Geiger Climate Classification in Asia-Pacific as of April 2006

Thailand located at 13.9202° N, 101.0168° E, is the world's 50th largest country in terms of total area (slightly smaller than Yemen and slightly larger than Spain), with a surface area of approximately 513,000 km^2 (198,000 sq mi), and the 21st most-populous country, with approximately 64 million people. The largest city is Bangkok, the capital, which is also the country's center of political, commercial, industrial and cultural activities. Thailand's climate varies by region, and the following covers just the Bangkok central region and the north and northeast. The peninsular in the south is less predictable and more subject to variations. Thailand's climate is tropical, but not oppressively hot as in some other tropical countries around the world. The seasons are determined by the "monsoons", which are consistent wind patterns that change at different times of the year due to the differences between land and sea temperatures and pressures.

The seasons are as follows:

- November thru February - Dry, "Cool" Season - Winds are predominantly from the north when this season starts. Daytime high temperatures are between 30-35 C (85-95 F), humidity between 50% - 60%. Every day is a sunny day. The ground will still be saturated in many places in November due to the previous rainy season. This is the season to travel around Thailand.
- March thru June - Hot Season - Temperatures can soar to 40 C (105 F) on the hottest days, and at night the humidity rises. Sometime between late June to late July, evening downpours start to come.
- July thru October - Rainy Season - By "rainy", we are talking about evening downpours. It rarely rains for more than an hour at a time. The mornings are usually sunny, but a thunderstorm or two can come towards the late afternoon or at night. This usually starts in late July or August, but by September there is a thunderstorm on most days, often resulting in flooded streets but cooler nighttime temperatures. Because Bangkok is flat, you rarely find any place with more than a foot of water, and it usually drains away slowly in a few hours. By late September and October, the major rivers are high and there is sometimes permanent flooding along the river, sometimes quite deep. There is a massive investment in pumps to manage the problem, but sandbagging of economically valuable areas and flooding of adjacent areas is not uncommon. This season usually ends suddenly in late October when the winds suddenly change to the north.

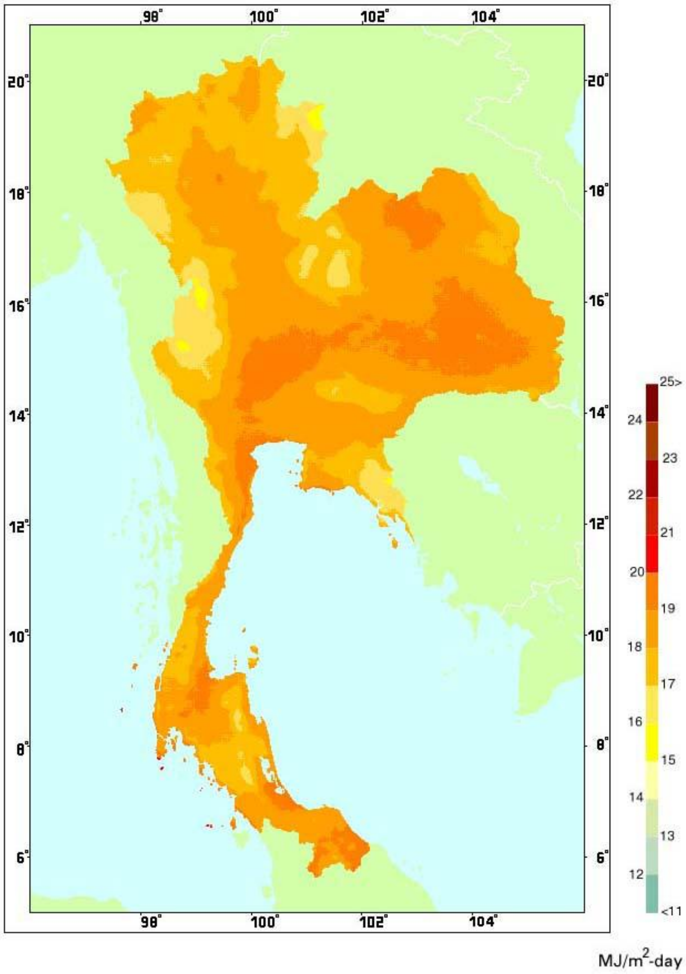

Figure4.2: Solar Energy in Thailand
Source: Department of Alternative Energy Development and Efficiency, Ministry of Energy, 1999

Solar Energy in Thailand has relatively high potential. The distribution of solar radiation intensity at various places in Thailand for each month is influenced by the Northeast Monsoon and Southwest Monsoon. The majority of the country receives the maximum solar radiation during April and May with values ranging from 20 – 24 MJ/m^2-day. Considering the daily solar radiation for an annual average, we found the areas with the maximum solar radiation to be at the northeast and some parts of the central region which the solar radiation receiving of 19 – 20 MJ/m^2-day as an annual average and such these areas are accounted for 14.3 percent of an overall country, 50.2 percent of the total area receiving an annual average of solar radiation at 18 – 19 MJ/m^2-day. The total daily solar radiation of an annual average in an overall country area has a volume of **18.2 MJ/m^2-day**. These results indicate high potentials of Thailand's solar energy.

4.2 Microclimate in Bangkok

The Bangkok Metropolis is located at 13°44′ N and 100°34′ E. Concern about climate change may seem to be a relatively new phenomenon, but it has been a subject of discussion since the nineteenth century, when a few scientists began to realize that some gases in the atmosphere were causing a greenhouse effect that was raising temperatures on earth. Carbon dioxide was the focus of the early investigators. When scientific instrumentation became reliable enough to produce meaningful results from atmospheric and oceanographic testing, scientists concluded that the levels of carbon dioxide were indeed rising fast.

The variations in maximum and minimum temperatures in Bangkok during the previous 10 years, compared with long-term averages, found that from 1991 to 2000 (figure 4.3) revealed that the maximum average temperature in the summer months was significantly higher than the long-term average. Conversely, the lowest temperatures in the winter months were warmer than the long-term average (Department of Meteorology, 2008).

MONTH	January	February	March	April	May	June	July	August	September	October	November	December
Average daily maximum Temperature (oC)	32	33	34	35	34	33	32	32	31	31	31	31
Average daily minimum Temperature (oC)	20	22	24	25	25	24	24	24	24	24	22	22
Average total rainfall (mm)	8	20	36	58	198	160	160	175	305	206	66	5
Average number of rainy days	11	3	3	9	10	13	13	15	5	14	5	1

Figure4.3: Climate of Bangkok
Source: BMA 2005 Refer to BBC Weather Centre, 2005

4.2.1 Temperature and rainfall trends in Bangkok

The average maximum temperatures observed in Bangkok indicate an increasingly warming trend over the period 1961-2007 (see Figure 4.4). The pattern of warming is also observed in the average minimum temperatures in Bangkok during the same period, as shown in Figure 4.5. In urban Bangkok, the number of days exceeding 35^{0}C is rising (see Figure 4.6). The impacts of climate change on Bangkok have thus become increasingly visible and have been the subject of serious concern among residents since 1967, as they experience increasingly hotter weather (Department of Meteorology, 2008).

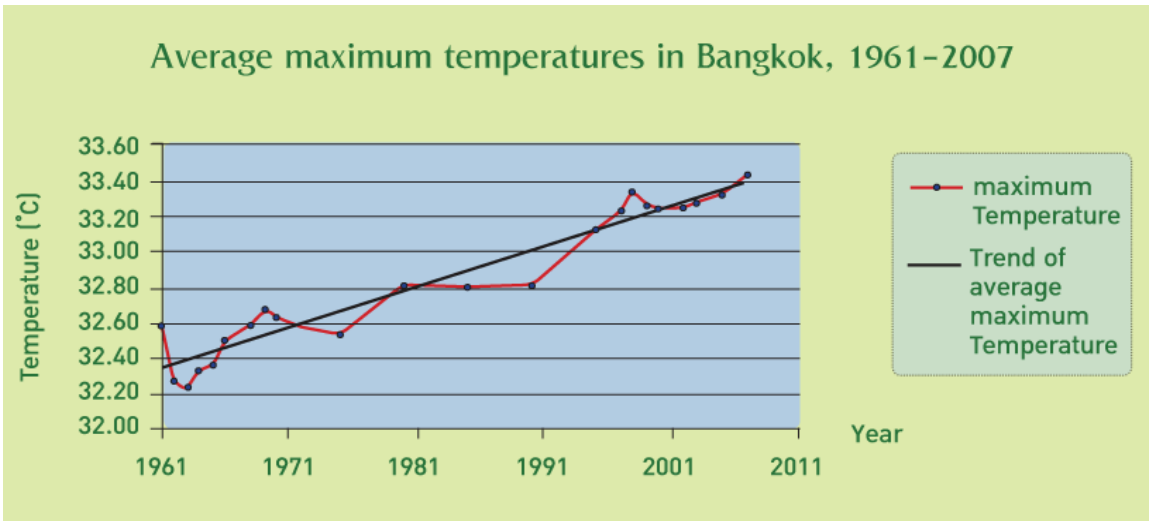

Figure 4.4: Average maximum temperatures in Bangkok, 1961-2007
Source: Department of Meteorology, 2008

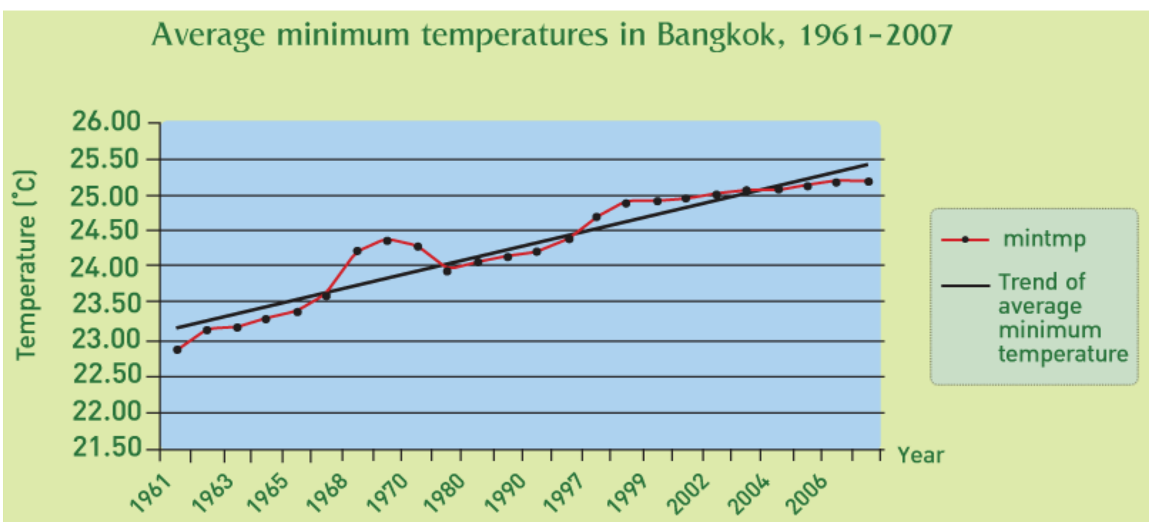

Figure 4.5 Average minimum temperatures in Bangkok, 1961-2007
Source: Department of Meteorology, 2008

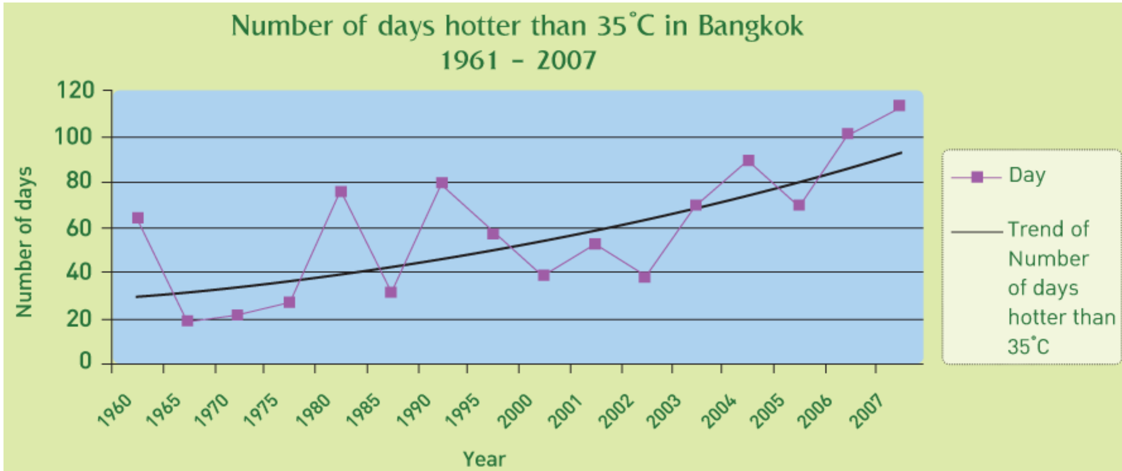

Figure 4.6: Number of days exceeding 35^0C in Bangkok, 1961-2007
Source: Department of Meteorology, 2008

The average annual rainfall in Bangkok and vicinity is 1,482 mm. The observed monthly rainfall variation pattern for the entire year during the period 1999-2006 (see Figure 4.6) shows that there are two peak rainfall patterns concentrated in the months of May-June and September- November. In 1999 the maximum rainfall peaked during May and in 2001 the peak was unusual, occurring during October. These rainfall patterns suggest extreme rainfall events occurring in certain months of the year.

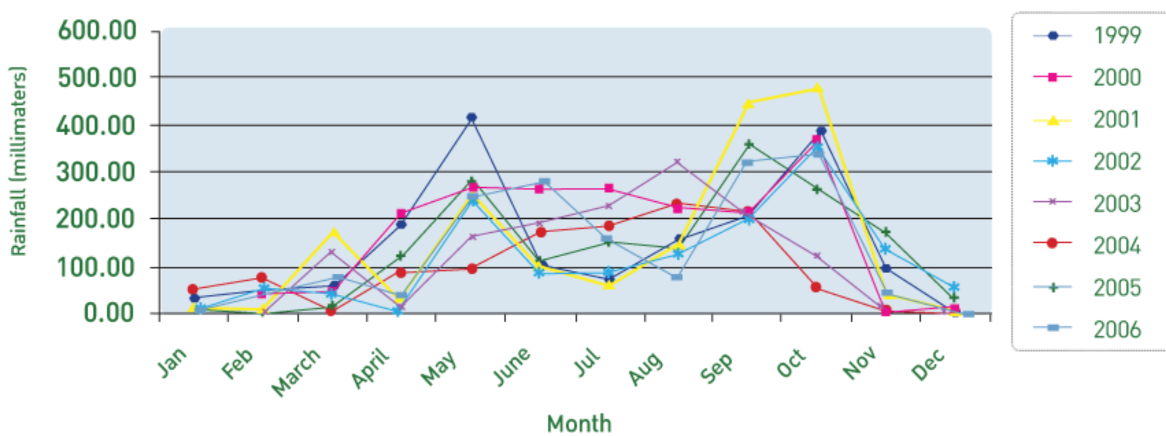

Figure4.7: Variations in monthly rainfall in Bangkok
Source: Department of Meteorology, 2008

4.2.2 Wind Study in Bangkok

The climate of Thailand is a tropical climate which is commonly known as hot and humid. Discomfort due to heat and humidity is the dominant problem. Wind is also one of the most climatic elements, which affects comfort inside a building. Wind has a twofold influence on the thermal system of a building: by the thermal surface resistance and the ventilation rate. With open windows, outside wind speed also influences the air movement inside a room, therefore affecting the thermal comfort. Thus, the knowledge of wind direction, speed and frequency throughout the year is an important factor to consider as it can effectively negate the discomfort arising from high humidity and temperature.

The report study of Building Scientific Research Center, conducted by Jompob Waewsak, Joseph Khedari, Rangsit Sarachitti and Jongiit Hirunlabh, shows the wind velocity frequency distribution curves and wind direction map in Fig. 4.7 and 4.8. From the wind velocity distribution curves, it can be seen that most of wind velocity occurs in the range of 1-3 m/s. The minor degree of wind velocity is above 4 m/s. Also, high wind speed is much less frequent. The wind direction map clearly demonstrates the effect of upper atmospheric circulation, especially southwest monsoon and northeast monsoon on the surface wind direction. Southwest monsoon plays an important role from May until September, whereas the northeast monsoon effects the surface wind direction from October until February. The southerly wind appears strong in March.

From Jompob Waewsak's analysis above, it can be deduced that the dominant surface wind velocity in Bangkok is 1-2 m/s approximately. Although southern and northern winds are more frequent, there is practically no prevailing wind condition all year round. Such characteristics limit the benefit of the use of wind as a "main" parameter for designing naturally ventilated building. Based on a simple statistical analysis, a correlation for determining surface wind velocity at an arbitrary time of the year was calculated. The direction of surface wind was strongly affected by the southwest monsoon from May to September and northeast monsoon from October to February. Strong southern wind appeared in March. The frequent wind velocity was about 1-3 m/s while the annual mean value is about 2.2 m/s. This clearly indicated that wind could not be used effectively to provide significant indoor air motion in Bangkok residential buildings including single house, row house and the like. However, the main benefit from this precedent is the guidance of building orientation for optimal natural ventilation in design using a simple correlation for calculating wind velocity in building simulation.

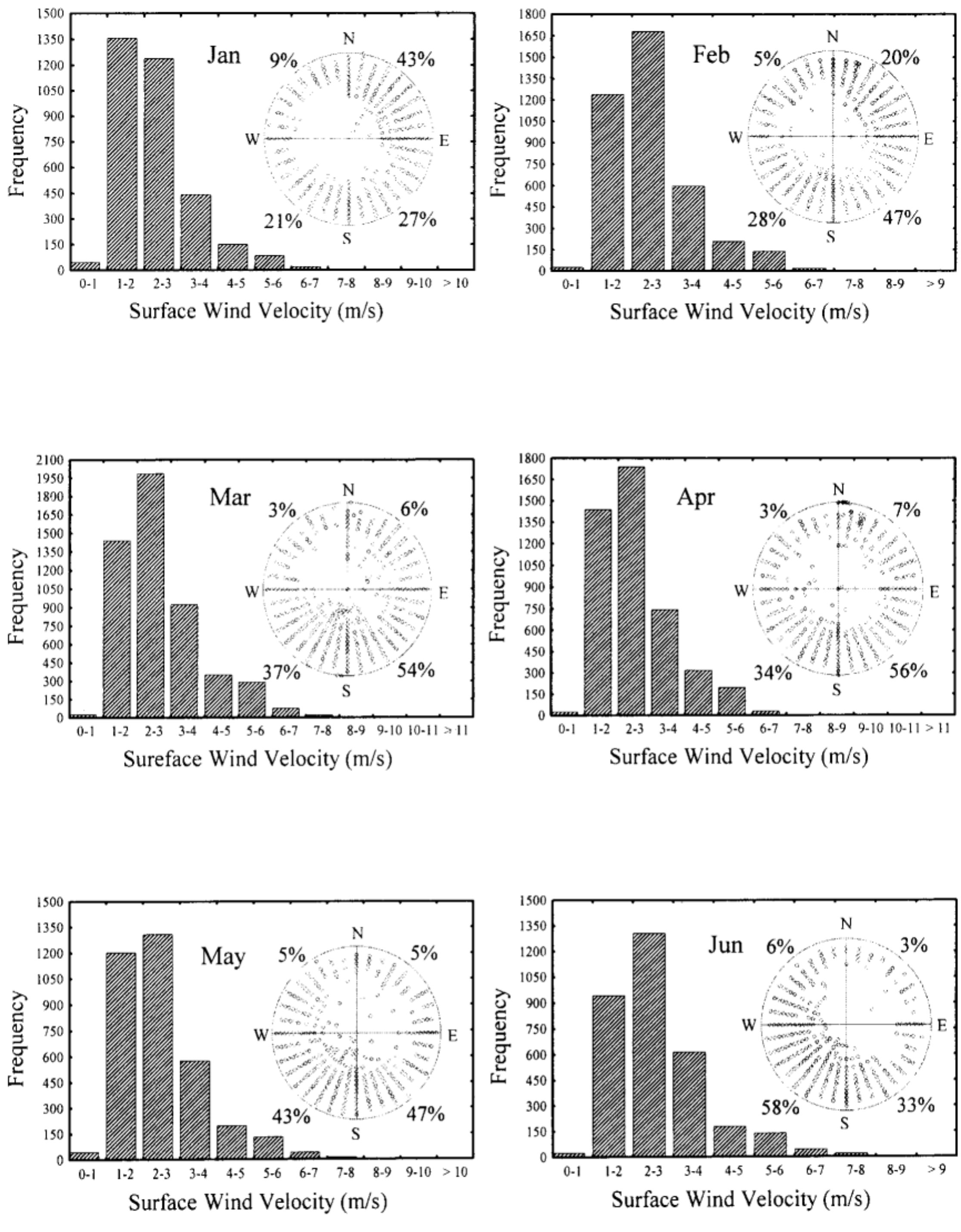

Figure 4.8: Surface wind frequency distribution and direction map (January-June)

Source: Direction and Velocity of Surface Wind in Bangkok, Building Scientific Research Center ThammasatI nt. J. Sc. Tech.,V o.7, No.1, January-April 2002

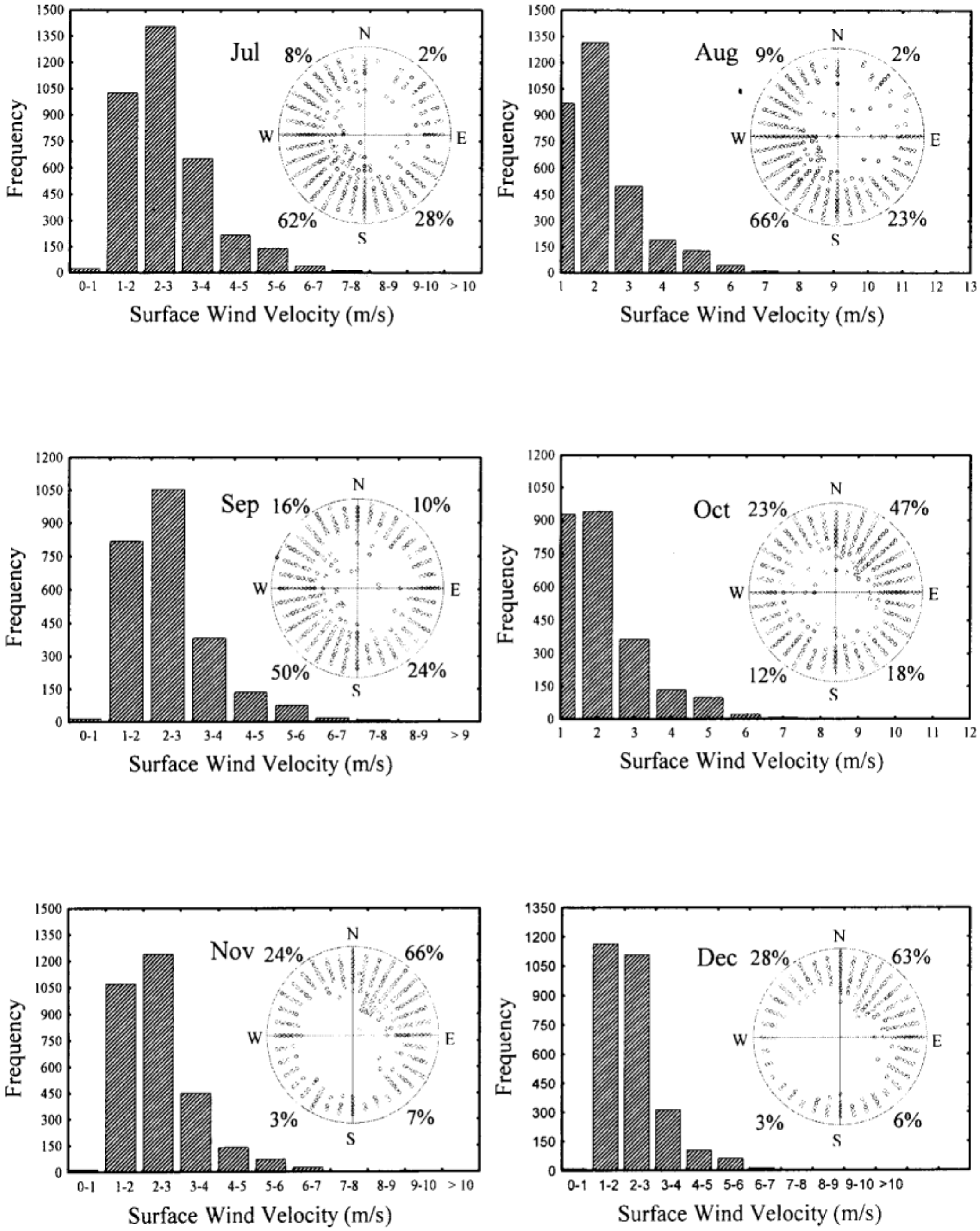

Figure 4.9: Surface wind frequency distribution and direction map (July-December)
Source: Direction and Velocity of Surface Wind in Bangkok, Building Scientific Research Center
ThammasatI nt. J. Sc. Tech.,V o.7, No.1, January-April 2002

4.3 Thailand Energy Situation

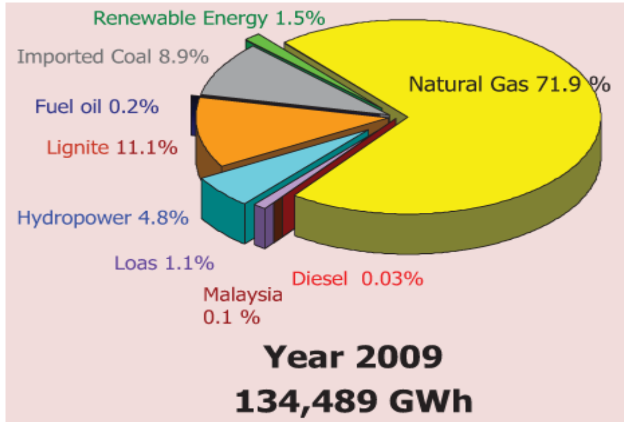

Figure 4.10: Thailand energy sources and share of power generation by fuel types
Source by: Ministry of Energy, Thailand, 2009

Thailand energy demand is 0.6% or 66.7 Million Tonnes of Oil Equivalent (mtoe), compared to the world energy demand, which is about 11,297.9 mtoe. Fossil fuel is the primary type of energy consumed in Thailand in addition to Natural Gas (Figure 4.10), which creates the GHG (Greenhouse gas) emission. The two primary sources of CO_2 emissions are from burning coal used for electricity generation and petroleum. Total amount of primary energy produced in the year is specified by all sources, i.e. hard coal, lignite/brown coal, peat, crude oil, natural gas liquids (NGLs), natural gas, combustible renewables and wastes, nuclear, hydro, geothermal, solar and the heat from heat pumps that is extracted from the ambient environment (Ministry of Energy, 2009). In Thailand, the energy demand is aimed to increase within the next few years. The Ministry of Energy proposed future energy of Thailand should be established through more coal and nuclear power plants, which are parallel with renewable energy sources.

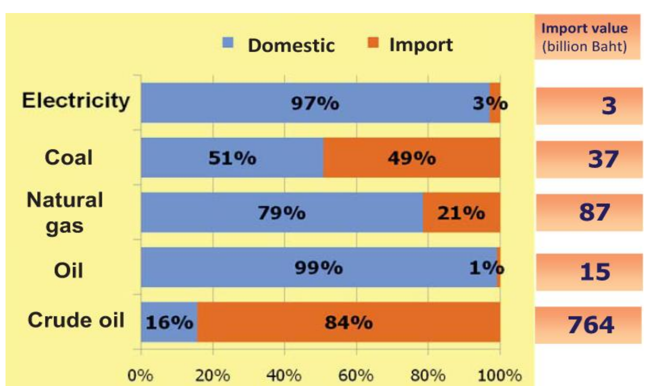

Figure 4.11: Thailand domestic and import energy sources
Source by: Ministry of Energy, Thailand, 2009

Although Thailand relies heavily on imported energy (Figure 4.11), the energy security of the country has been maintained through a diversity of types and sources of energy. Fossil energy still plays a major role, especially petroleum products and natural gas. Renewable/alternative energy will be the main energy resource next to fossil energy. Biomass, which has been mostly used as fuel in rural households and industries, will have a greater role as fuel in power generation and as an energy source for bio-liquid fuel production for vehicles. Most of the renewable energy types have proved to be environmentally friendly. Therefore, promotion of renewable energy technology research and development is considered to be of great importance and will continue to be supported by the government.

Electricity	Current (MW)	2008-2011	2012-2016	2017-2022	Total	%
Mini-Hydro	67	165	281	324	5,608	2.4%
Wind	5.13	115	375	800		
Solar	38.6	55	95	500		
Bio-Mass	1,644	2,800	3,220	3,700		
Bio-Gas	79.6	60	90	120		
Waste	5.6	78	130	160		
Hydrogen	-	0	0	3.5		
Heat/Thermal	Current (ktoe)					
Solar	0.5	5	17.5	38	7,433	7.6%
Waste	1.09	15	24	35		
Bio-Mass	3,071	3,660	5,000	6,760		
Bio-Gas	201	470	540	600		
Bio-Fuel	Current (M.Ltr /Day)					
Ethanol	1.2	3.00	6.20	9.00	9.00	4.1%
Bio-Diesel	1.6	3.00	3.64	4.50	4.50	
Nat. Gas	Current (M. cu.f/Day)					
NGV	147	3,469	5,260	6,090	690	6.2%
						20.3%

Figure 4.12: Renewable Energy Development Plan (REDP) 2008-2022
Source by: Ministry of Energy, Thailand, 2009

Renewable Energy Development Plan (REDP) in 2008-2022 (Figure 4.12) is mostly derived from natural resources and hence considered clean and environmentally friendly. However, there exist some hindrances to the development of renewable energy and the costs of harnessing renewable energy resources are still high compared with the costs of using commercial energy, particularly, the development of solar and wind energy which require the use of high cost technology. Renewable energy that has high potential to be used in place of fossil energy includes hydropower, biogas and biomass energy, solar energy and geothermal energy. Studies and development on these energy sources have continuously been undertaken by several agencies, both at the local level initiated by local intellect and at the government level. Presently, the development of renewable/alternative energy has become a focus of interest and wider utilization has been promoted to replace conventional energy consumption in parallel with the efforts to stimulate people to use energy efficiently and economically.

4.4 Bangkok Energy Consumption

"Bangkok Metropolitan Administration, being aware of the global warming crisis and the necessity to take initial action to be part of the global effort in mitigating the problem."[1], Apirak Kosayodhin (Former Governor of Bangkok). The Bangkok Metropolitan Administration (BMA) has prepared the Action Plan on Global Warming Mitigation 2007 - 2012, which comprises of 5 initiatives. This action plan aims at GHG emission reduction by at least 15% of the total GHG emission anticipated in the year 2012 under business as usual projection. Although Thailand is not bound to international commitments to reduce greenhouse gasses (GHG) emissions, such as mandated for developed countries in the Kyoto Protocol under United Nations Framework on Convention for Climate Change, the Bangkok Metropolitan Administration believes it nevertheless must begin to take action to reduce its contribution to the global warming problem. GHG emission levels from the Bangkok metropolitan area are relatively high when compared to other large cities, even those in developed countries. (See Table 4.1)

City	Estimated CO_2 Emission (million ton p.a.)	Estimated Population (million)	Estimated CO_2 Emission Per Capita (ton per capita p.a.)
San Diego	13	2.9	4.5
Tokyo	71	12.4	5.7
London	44	7.5	5.9
Bangkok	***42.65***	***6.0***	***7.1***
New York	58	8.2	7.1
Toronto	24	2.5	9.6
San Franscisco	8	0.7	11.4

Table 4.1: Comparison of GHG Emission of Bangkok and Other Major Cities
Source: Bangkok Metropolitan Administration, Action Plan on Global Warming Mitigation 2007 – 2012

[1] Action Plan on Global Warming Mitigation 2007 – 2012, BMA

4.4.1 Green House Gas Emission Inventory

The Bangkok Metropolitan area, being Thailand's major center for socioeconomic activities, consumes approximately 29,200 GWh of electricity annually, which is equivalent to 14.86 million tons of CO2 emissions. Additionally, transportation in Bangkok is dominated by the use of CO2- producing vehicles (table 4.2). The Department of Energy Business, Ministry of Energy, estimates that Bangkok's transportation sector consumes approximately 28 million liters of gasoline per day, which is equivalent to approximately 21.18 million tons of CO2 emissions annually. Combined, energy and transportation are responsible for 84% of Bangkok's GHG emissions. Methane from solid waste landfill and wastewater is another source of GHG emissions in Bangkok, estimated at 1.13 million tons of CO2 equivalent annually or 3 percent of total emissions. The remaining 13 percent of Bangkok's GHG emissions are from miscellaneous sources such as rice fields, canals, etc., totaling 5.58 million tons of CO2 equivalents annually. (See Table 4.2)

Sector	**CO_2 Emission (million ton p.a.)**	**%**
Electricity	14.86	34
Transportation	21.18	50
Waste / Wastewater	1.13	3
Other Sources	5.58	13
Total	**42.75**	**100**

Table4.2: GHG Emission in Bangkok by Sectors
Source: Bangkok Metropolitan Administration, Action Plan on Global Warming Mitigation 2007 – 2012

Academics and experts from various disciplines then used the information collected to analyze the draft plan's appropriateness, feasibility and potential effectiveness toward reducing GHG emissions. This final Bangkok Metropolitan Administration Action Plan on Global Warming Mitigation contains 5 initiatives:

- Initiative 1: Expand Mass Transit and Improve Traffic Systems
- Initiative 2: Promote the Use of Renewable Energy
- Initiative 3: Improve Electricity Consumption Efficiency
- Initiative 4: Improve Solid Waste Management and Wastewater Treatment Efficiency
- Initiative 5: Expand Park Areas

The Action Plan is aimed at bringing about, over the next five years, a ***15 percent reduction***[2] in Bangkok's GHG emissions below currently projected 2012 emission levels.

4.4.2 Improve Building Electricity Consumption Efficiency

Improving the building electricity consumption has become a major role for the electricity efficiency in Bangkok. The electric power consumption in public building and private household in Bangkok is estimated at approximately 29,200 GWh per year, which is primarily used for air conditioning and lighting. This level of consumption generates approximately 14.86 million tons of CO2 emissions annually. The GHG emission from this sector could grow up to 16 million tons per year by the end of 2012 if no efforts are undertaken to control electricity consumption. (See Figure 4.14) A campaign by the Bangkok Metropolitan Administration aims to reduce electricity consumption, thereby reducing GHG emission. The campaign proposed a five year estimate to achieve their goals, which was derived from the Energy Conservation Measures Guidance for New Buildings Code by the Energy Policy and Planning Office, Ministry of Energy.

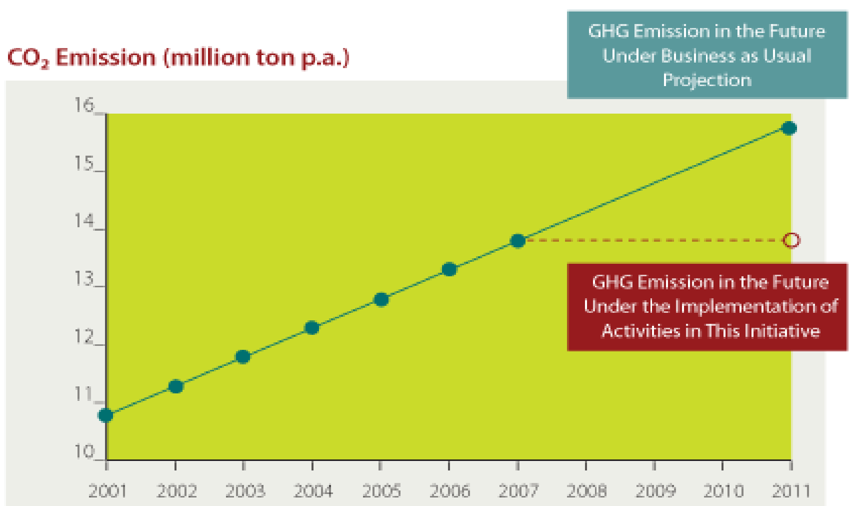

Figure 4.13: GHG Emission from Bangkok's Electricity Consumption Under Business as Usual (BAU) Projection Compares to Emission Resulting from the Implementation of This Action Plan
Source: Bangkok Metropolitan Administration, Action Plan on Global Warming Mitigation 2007 – 2012

[2] Action Plan on Global Warming Mitigation 2007 – 2012, BMA, page 21

The Bangkok Metropolitan Administration has proposed the action plans and activities under this Initiative 33, which aims to reduce the electricity usage in Bangkok. This policy has gained a high percent of acceptance in Asian Green City Index (see Chapter 6) in term of environmental governance. The fact is BMA does not show a specific implementation beyond written intention in the energy performance. The number on table 4.3 demonstrates that the GHG reductions estimates are based on the figure of 0.509 kg CO2 per 1 KWh of electricity savings as contained in the Study on Electricity Sector Baselines in Thailand (See Table 4.3). The table below presents merely a holistic idea of how to save energy. The action plan has to be considered and criticized. A more elaborate discussion will be presented in section 4.5

Activity	Target Energy Saving (GWh p.a.)	GH Reduction- CO_2 Equivalent (million tons p.a)
Action Plan 1		
Activity 1.1: Improve Energy Efficiency in All BMA Buildings	16	0.01
Activity 1.2: Promote and Support the Implementation of Energy Conservation Scheme in Privately Owned Buildings	821	0.42
Action Plan 2		
Activity 2.1: Campaign for Efficient Use of Electrical Appliances	1,370	0.7
Activity 2.2: Campaign for Reduced Use of Air-Conditioning Systems	797	0.41
Activity 2.3: Support Energy Efficiency Labeling of, and Proper Maintenance Scheme for, Electrical Appliances	872	0.44
Activity 2.4: Activity 2.4: Promote the Use of Energy-Saving Appliances	265	0.14
Activity 2.5: Promote the Use of Energy-Saving Light Bulbs	250	0.13
Total	**4,391**	**2.25**

Table4.3: Target GHG Emission Reduction according to Action Plans
Source: Bangkok Metropolitan Administration, Action Plan on Global Warming Mitigation 2007 – 2012

[3] Action Plan on Global Warming Mitigation 2007 – 2012, BMA, page 21

4.4.3 Impact on Water Resources

The Metropolitan Waterworks Authority (MWA) supplies about 4.65 million cubic metres (Mm3) of purified water per day to residential, industrial and commercial users in Bangkok, uses surface water withdrawn from the Chao Phraya and Mae Klong rivers. This represents 91 percent of the city's total demand (BMA, 2006), with the remaining 9 per cent (about 0.5 Mm3/day) ~~is~~ met by extraction of water from deep wells (Polprasert C., 2007). The effects of global warming have caused the river flows in Thailand to be unreliable, with too high or too low flow rates during the rainy and dry seasons, respectively. The projected changes in water supply may be further exacerbated by increasing demand. Heavy pumping of ground water has resulted not only in land subsidence in most areas of Bangkok but also ground water contamination with saline intrusion, nitrates, coliform bacteria and volatile organic compounds (BMA, 2004).

4.4.3.1 Present Water Situation[4]

- Surface Water Contamination: The canals are presently highly polluted due to direct discharge of wastewater throughout the city area. Although large buildings are required to have some form of wastewater treatment, and also small private houses are required to have at least septic tanks to receive toilet wastes, domestic wastewater are mostly discharged to public drains without treatment.
- Groundwater Contamination: Since septic tank cannot provide treatment efficiencies higher than 30-40 %, the discharge of the effluents created environmental problem to receiving surface water. The soil in Bangkok is clay in nature with low permeability value of the order of $10x10^{-7}$ cm/sec. The groundwater table is high and as a result, the leaching pits do not work properly. There is a possibility of constant exchange of flow between groundwater and the leaching pit wastewater, leading to an increased probability of groundwater contamination and higher water levels in the pits.

- Drinking Water Supply and Management: the Metropolitan Waterworks Authority (MWA) produces water supply based on the demand, at the average of 3.8 million cubic meters per day. Almost 85% within the service areas under the responsibility of MWA are accessible to water supply although the authority has to face problems of fresh water shortage and deterioration of water quality in the drought period. Improper

[4] Water Pollution in Bangkok report, Bangkok State of the Environment 2001

wastewater treatment and disposal of domestic, agriculture and industrial wastewaters at the upstream of Chao Phraya River cause these problems. Fresh water is limited natural resources whilst there are various water users such as agriculture, navigation, and water supply. No doubt that the crisis on competing for water is getting more and more serious.

Since Bangkok is expected to continue to grow over the next 10 years, the problems of water supply and contamination of both surface and ground waters will also be exacerbated. By the end of the current century, increasing temperatures are expected to boost the demand ~~for~~ of water for agricultural purposes 2 to 13 times in the lower and medium warming ranges, respectively, and for household purposes. Some options that could be considered to mitigate Bangkok's increasing water demand might include: the harvesting of rainwater, decentralizing the wastewater management system, increasing stakeholder participation and raising awareness among consumers about water issues. With an average annual rainfall of 1,650 mm per year and an assumed rate of 10 percent efficiency in rainwater harvesting, Bangkok could utilize 0.7 Mm3/day of rainwater, which is equivalent to the amount of water extracted from deep wells (BMA, 2006). Such a practice would help to mitigate the problems of land subsidence, ground water contamination and dependence on surface water sources. If more rainwater could be harvested, this would help to reduce the flooding which occurs frequently in Bangkok during the rainy season. The trend in monthly rainfall in Bangkok during the period 1999-2006, illustrated in figure 4.7, provides an indication of the potential for rainwater harvesting in the city.

4.5 Summary of Bangkok Metropolitan Administration Adaption Actions Plan[5]

Policy

- Undertake risk assessments for all of Bangkok and at the district level for each level of administration in order to identify the most significant areas at risk and to establish priorities for dealing with them;
- Incorporate potential climate change adaptation actions into strategic city planning, where appropriate.

New buildings and infrastructure

- Where practicable, adopt climate-sensitive building designs that consider local coding and ventilation requirements, e.g. inclusion of natural ventilation coding, consideration of building orientation and low energy consumption;
- Design buildings to enable consideration of future climate change impacts and incorporation of future adaptation, e.g. inclusion of flood damage mitigation, appropriate low-energy consumption and water storage, and increased use of insulating materials in construction.

Existing buildings and infrastructure

- Monitor changes in the condition of structures so that any modifications or retrofitting occur on time and prior to failure;
- Identify alternative options should there be adverse impacts on existing buildings and infrastructure in order to maintain services and connections, e.g. minimize the isolation of communities during an adverse storm event that might put the infrastructure at higher risk;
- Launch an energy-saving program as has been done in Bangkok to retrofit buildings, including high-rise structures, as part of the efforts to reduce carbon emissions by 15 percent by 2012.
- Community health and recreation
- Establish the levels of risk communities may face from climate change impacts in order to assist in prioritizing potential action;
- Control planning and activities in areas of high risk;

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[5] Bangkok Assessment Report on Climate Change 2009, 65-67

- Encourage the design of buildings and public spaces that provide improved levels of thermal comfort and security, e.g. protection during floods and extreme weather events.

Natural environment

- Analyze the risks revealed by the initial risk assessment, such as the likelihood of floods, storm surges, drought and risks to the security of the water supply;
- Reduce other forms of external stress, such as pollution

The Bangkok Metropolitan Administration has proposed the action plans and activities under which aims reduce the environmental impact; but there is no visible implementation on policy's strategies and methodologies, merely written policy. The next step in Bangkok's energy movement is unclear. Whether or not the country will take a serious action towards energy efficiency is left up to policy makers, planners, and designers. Nevertheless, BMA has presented the intention of energy saving and energy conservation (figure 4.14), which provides the opportunity for better building standard and positive impact to environment. I believe BMA's research ties into my thesis goal. The thesis outcome will be a new standard for high performance high rise building, which will be a good public example of energy sufficiency and productivity. The high rise standard will consist of benchmark designs aimed at shifting Bangkok, as well as the greater area of Thailand, towards a more energy efficient metropolitan.

Climate change impact	Adaptation measures		
	Community infrastructure, operations	Business and commercial	Residential health and general population
General long-term rising temperatures of 3-5˚C	• Urban design • Tree planting • Water conservation • Insect and pest controls	• Actions to reduce a "heat island" effect, such as building design and green space • Agricultural techniques	• Better insulation • Design for efficient cooling • Pest, insect controls • Water conservation
Ground and surface water quantity and quality	• Water use restrictions, such as the imposition of fines during periods of water shortage • Optimize reservoir releases (based on historical data and drought anticipation) • Expand storage capacity • More realistic water pricing or greater regulation of withdrawals of surface and ground water	• Water efficiency and conservation programmes • Water pricing (marginal cost pricing to replace average cost pricing, use of water metering) • Irrigation practices • Revise shipping and tourism regulations	• Water efficiency and conservation programmes, such as reducing volume of toilet flush, installing residential water conservation technologies • Irrigation practices
Sea level rise, especially in Bang Khuntien District of Bangkok	• Land use planning • Construction or improvement of levees, dykes • Water reservoirs, waste discharge designs	• Coastal protection phased retreat • Harbour/port operation and engineering	• Land use planning • Ecosystem protection
Extreme weather-related events (wind storms, prolonged rain, river flooding, drought)	• Emergency preparedness plans • Construction or improvement of levees, dykes • Elevate buildings • Land use planning (e.g. consider adequacy of flood plain zones) • Diversify power supply • Upgrade transmission lines • Implement tree-trimming policy • Strengthen emergency communications	• Emergency preparedness plans • Flood proof buildings • Elevate buildings • Reschedule production and marketing • Business resumption and restoration planning	• Emergency preparedness plans • Flood-proof homes, build elevated basements, move power-supply boxes upstairs • Publicly sponsored flood insurance (for areas outside of flood plains) • Advocate 72 hours of self-sufficiency (such as having emergency supplies on hand, canned food, water, medical, back-up power supplies, generator, fuel, radio with batteries)
Increased frequency and intensity of short-duration heavy rains	• Increase the size of storm drains, culverts, bridge openings etc. • Increase water-absorbing capacity of urban landscape	• Increase water-absorbing capacity of large paved areas	• Ensure that storm sewers are clear of debris • Launch storm-sewer protection programmes • Increase attention paid to landscape design for reducing rapid run-off
Increased frequency and intensity of heat waves, droughts and smog episodes	• Heat contingency plans • Use of air conditioners • Water and energy conservation measures • Air pollution abatement • Reduction of urban traffic • Planting more trees	• Use of air conditioners • Rescheduling of production in some cases • Elevate buildings • Reducing energy and water consumption and air emissions	• Hospital emergency preparedness • Education on what to do in the event of a heat wave (reduce exercise, consume liquids, stay indoors etc.) • Use of residential air conditionersradio

Figure 4.14: Adaptation measures for Bangkok
Source: Bangkok Metropolitan Administration, Green Leaf Foundation and United Nations Environment Programme 2009, Bangkok Assessment Report on Climate Change 2009. Bangkok: BMA, GLF and UNEP

Chapter 5

Site Context and Market

5.1 Significance of Sukhumvit District, Bangkok Thailand

Sukhumvit Road serves as a main commercial street, and this section is often congested, even at late evening hours. After the World War II, this area became developed with large contemporary villas catering to the upper class. As property values kept rising, bought more and more land and capitalized on them by constructing big apartment high-rises. The construction of the Bangkok Mass Transit System (BTS) - which includes the Skytrain in 1999 that covers most of Sukhumvit Road, Bangkok's Mass Rapid Transit (MRT) metro system in 2004, and ~~also~~ Bangkok's newest public transportation system, ~~is~~ the Airport Rail Link in 2010 - directly reaches Sukhumvit, increasing the popularity of this district even more. With a high density of population and major commercial businesses, the street produced rapidly high temperature and required more energy to support daily and nightly activities. Sukhumvit district will be a challenging site with its high constraint and negative impact from urban heat island (UHI). According to the latest survey, conducted from July to September by the Bangkok Metropolitan Administration (BMA), the air on Sukhumvit has over 300 micrograms of dust particles per cubic metre (mpcm), far above the standard of 120 mpcm; source from The Nations News, published November 25, 2007.

Nevertheless, Sukhumvit area is a target of my research which is aimed to set up the prototype High-Rise residential design that will increase awareness of the significance of high performance building design. In addition, Sukhumviit district has a high potential ~~in~~ for real estate development in both commercial and residential sector for tall buildings. This opportunity plays an important role for future development projects which take environmental and sustainable approaches to reduce GHG, Co2, and carbon emission, thereby increasing human health and quality of life. The Sukhumvit area is quite unique because it is the center ~~of~~ for high commercial and residential buildings lending itself for high levels of economic growth, population density and development. In the next section, we will examine three sites and extract key factors for baseline consideration for building design framework.

5.1.1 Contextual Factors

Figure 5.1: Sukhumvit area macro scale map shows infrastructure diagram (BTS, MRT, and Airport link) and site study examples (A –C).

Figure 5.1 shows the macro district transportation map around Sukhumvit road. BTS (Bangkok Mass Transit System) is a major elevated rail on the main Sukhumvit road and underground train; MRT (Mass Rapid Transit) crosses over a part of Sukhumvit road, along with other types transportation. This matrix of transit and transportation is the main reason for high levels of Co_2 emission and of GHG in the high density metropolitan area with little green space. Context condition, demographics and quality of life are all factors in the design of tall buildings. Since Sukhumvit district has the largest percentage of tall buildings, it is an obvious space for commercial business enterprises, and residential towers. Multi-use tall buildings, where typically commercial and residential uses are combined, are also very prominent in this district.

Figure 5.1 presents case studies of site A, site B and site C, all of which are located along the major Sukhamvit road and paralled with the BTS In examining the three sites, we are able to understand the micro climate and context condition and define the key factors that influence tall building design.

Figure 5.2: Site examples (A and B) show surrounding and context condition.

Considering that sites A and B are adjacent to one another, we can assume that they have similar site conditions. There are arbitrary programs in this location with commercial and mixed-use buildings along the front street of the major Sukhumvit road, which integrates vehicles with pedestrians. The BTS sky train is located on the north above both sites A and B, which is elevated up to 4th – 5th stories about 12 – 15 meters (40 – 50 feet height), (figure 5.3). The height of the sky train provides a great potential for commercial and residential development along this corridor. The surrounding buildings are composed of both high and low rise buildings with multiple functions (typically with offices and commercial in front and residential in the back). In this context, we are able to assume that in the coming future, tall buildings will be built adjacent to each other on the Sukhumvit road and close to BTS. Predictably, high-rise buildings in future will be built on the east and west side (figure 5.2), which open up the opportunity for high view on only the north and south side of buildings. My research in High-Rise building design will consider high view situation as another site constraint~~,~~ for setting up the urbanistic tall building guideline.

Figure 5.3: BTS, condition comparing the building height (left) and underneath rail condition (right)
Source: http://en.wikipedia.org/wiki/File:BTS_Nana_Skytrain_Station.jpg

Figure 5.4: One way sub street between site A and B (left), Underneath BTS condition (right).
Photograph by: Theeprakorn Lunthomrattana, NaNa BTS Station, Bangkok, 01/28/2011

Figure 5.5: Site A and B surrounded by High-Rise and low-rise buildings
Photograph by: Theeprakorn Lunthomrattana, NaNa BTS Station, Bangkok, 01/28/2011

High density of urban block and urban building programs are shown in figure 5.2, where most high-rise and mixed use programs line the main Sukhumvit street. The pattern of massive buildings and multi-functions in close proximity reveals a trend for urban growth of taller buildings with mixed-use programs along this main corridor with a gradually lower building skyline as one move away from the main street. In other words, assuming a uniform urban grid, the tallest buildings start from the main infrastructure and descend in height as it is located further away. An ideal urban growth model emerged from the analysis of the existing site conditions (as depicted in figure 5.6) and will be used as the contextual situation for further analysis of building performance.

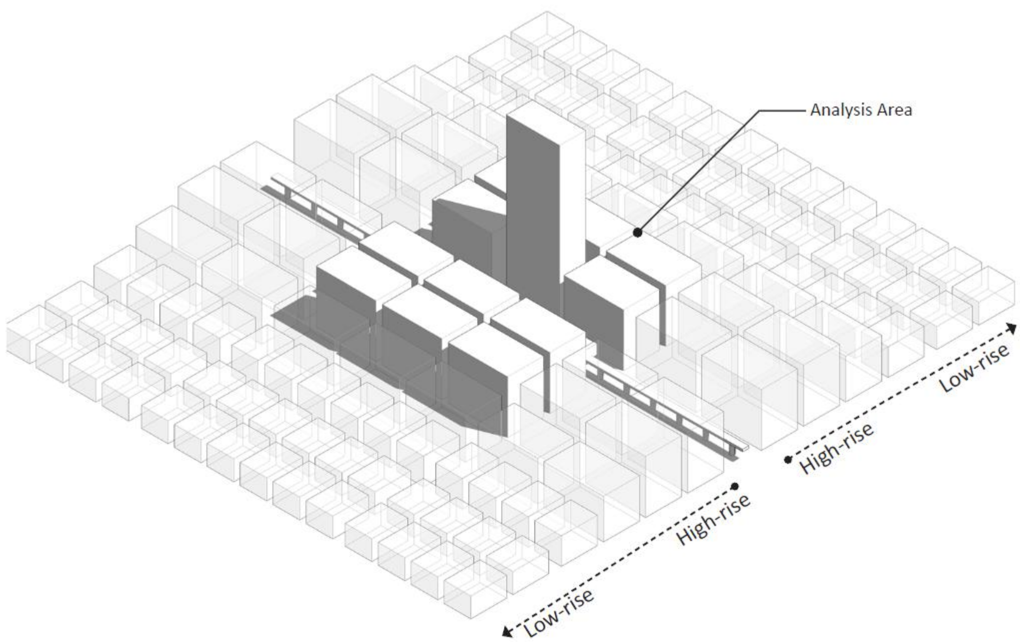

Figure 5.6: Ideal urban growth and model analysis

The diagram in figure 5.6 becomes a baseline for contextual study towards climatic and building design considerations. The target site design contains the tallest building and is surrounded by other high rises with the sky train in parallel to the main infrastructure. This situation presents the worst case scenario in high performance design for the target building and its adjacency. Further design strategies need to be addressed when taking this urban scenario into account.

5.1.2 Environmental Factors

Imagine the amount of Co_2 and CO emission in the high density areas of vehicles underneath of BTS without quality air movement and natural lighting underneath (figure 5.4: right). Low rise buildings from 3 – 4 stories high are directly impacted in this situation. Even though, the BTS can transport a mass group of people in a short period of time and successfully integrates with commercial circulation, the heavy structure of the foundation reduces the size of the road which has to maintain the same traffic impact. The local environment and its features are always one of the most critical considerations which drive the design of the built space. Design of ~~a~~ tall buildings in an urban environment requires careful selection of the site in order to integrate with the context and the open space around the building.

Figure 5.7: Traffic on Sukhumvit road (left) and pedestrians underneath BTS (right)
Photograph by: Theeprakorn Lunthomrattana, NaNa BTS Station, Bangkok, 01/28/2011

There is limited open space in Sukhumvit district. The district has green space which are located in the node or next to high shopping center. There is high level of UHIs in the areas with the least green space. Figure 5.7 reveals that there is not enough green space on pedestrian walkways and dark areas underneath the BTS. Traffic also influences the CO_2 emission more than in other locations. Also, sound pollution creates impact to the buildings in front the Sukhumvit road.

The orientation of buildings must be studied to provide minimum interference and to maximize views. In this context, views open opportunity in the north and south, to create a good ambient natural light from the north throughout most of the year except, during the summer. Adjacent tall buildings can significantly block the views and ventilation on both the East and West sides. Thus, the design will need to consider the building volume and geometry to provide better contextual natural performance. As for wind considerations, Chapter 4, figure 4.8-4.9 shows the influence of wind speed with an average of 1-2 m/s in a North and South orientation during the winter and summer season respectively. Tall buildings need to integrate passive design as much as possible to mitigate thermal storage (Chapter 2, figure 2.2). Undeniably, tall building designs in Sukhumvit district cannot only rely on passive design; the design aslo needs to integrate a high performance HVAC system in order to reach the satisfactory human comfort level. By respecting the natural potential of the site and integrating it with high performance HVAC; it is possible to achieve greater building performance.

5.1.3 Social-Economic Factors

Driven by social-economic factors, ~~in~~ Bangkok tends to look toward residential high-rises as the main strategy for urban development. During any building procurement process, the social needs of the neighbors should be high on the agenda. Any new high-rise development provides an opportunity to offer facilities and economic benefits for the surrounding community. Especially in areas close to BTS or other mass transit where the potential for economic gain is highest. BTS group capitalized on the potential for economic growth and is in the design phase of developing site B into a high-rise mixed-use building, Langham Place (figure 5.8).

Figure 5.8: Hotel exterior - The Langham Hotel and Residences Sukhumvit, Bangkok
Source: http://bangkok.langhamhotels.com/services.html

5.2 Bangkok Condominium Market

"Mass transit development will expand the urban reach of the city with more condominium units to be supplied in the urban area than the suburbs for the next few years."[1]

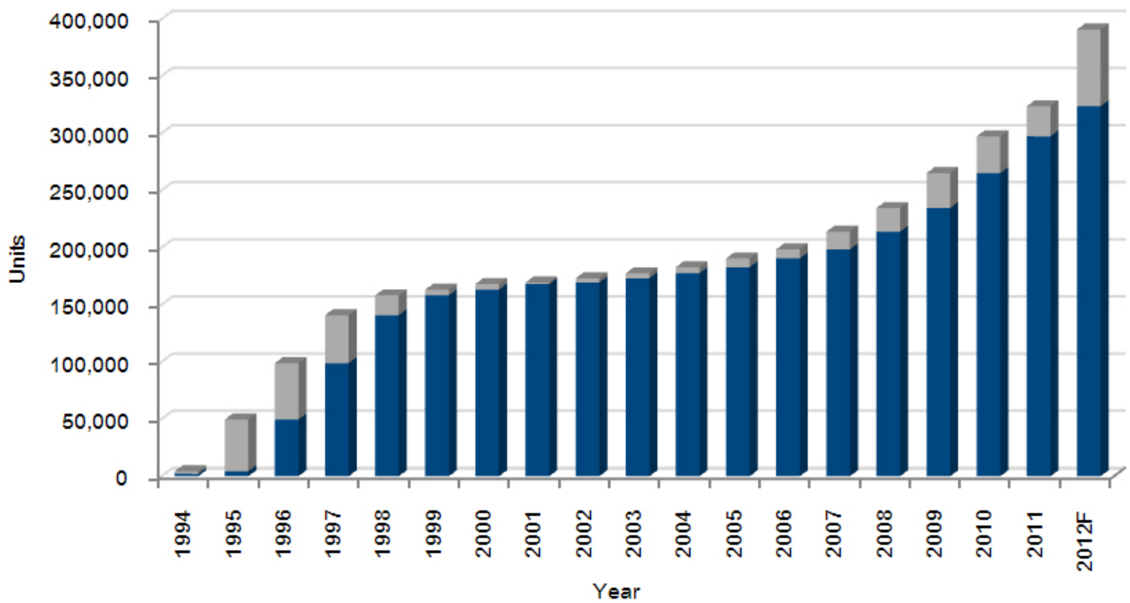

Figure 5.9: Supply of Apartment units in Bangkok 1994 - 2012
Source: Department of Land, Colliers International Thailand Research
Remark: The number of units does not include projects from the National Housing Authority

From Department of Land, Colliers International Thailand Research has announced around 11,440 new condominium units were completed and registered at the Department of Land in the first half of 2012. The total existing supply for the whole of Bangkok is approximately 335,300 units. More than 55,700 units are scheduled to be completed in H2 2012. The number of condominium units under construction and scheduled to be completed in 2012 is the highest since the Asian Financial Crisis in 1997.

The construction of the BTS and MRT lines influenced the location and project design of the new developments. Proximity to mass transit became a key factor and a more modern style of design was introduced suitable for the city lifestyle of the new burgeoning middle classes in smaller sized households. Affordability, unit size, layout and design have become increasingly important for developers in marketing their products.

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[1] Bangkok Condominium Market Report, 4th Quarter, 2009

Building Classification	Grade A	Grade B	Grade C
Location	close to BTs line	close to BTs / mRT line and BTs extension line	Reasonable proximity to BTs / mRT line, BTs extension line
Surrounding	easily accessible Tranquil atmosphere peaceful surroundings	easily accessible Good atmosphere Good surroundings	Hardly accessible poor atmosphere poor surroundings
Unit Specification	peaceful surrouGood building design, layout and decoration luxury materials and specifications	Good building design and decoration moderate building specification	Basic design
Facilities	comprehensive range of facilities	limited facilities	no/limited facilities
Parking Space Per Unit	≥100%	60 - 80%	< 60%
Property Management	professional management	professional / non professional management	non professional management

Table 5.1: Grading classification for condominiums
There is no official or officially recognized classification of condominiums. Colliers International Thailand scrutinizes every condominium project in Bangkok and provides a grade based on the criteria table 5.1

5.2.1 City Area (focused area)

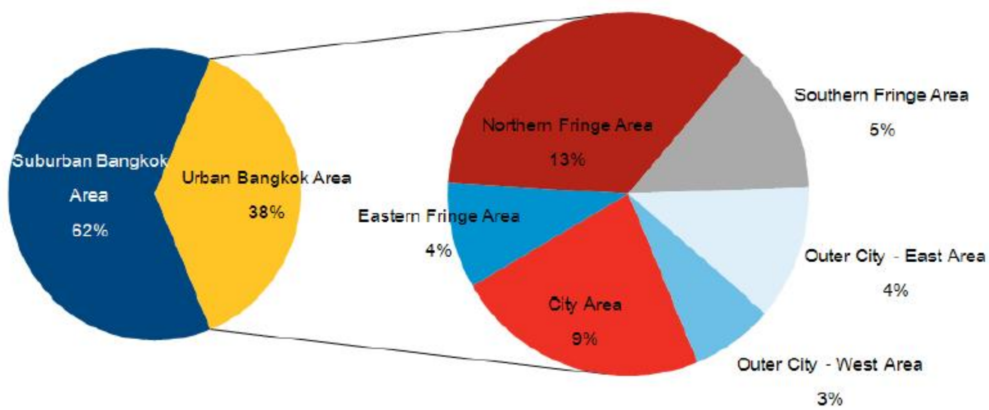

Figure 5.10: Total supply by location as of Quart 2nd, 2012
Source: Department of Land, Colliers International Thailand Research

The area covers four adjacent but competing sub-markets: the Sukhumvit section comprising Sukhumvit Road between Soi 1 and Soi 55 to the north and Soi 2 and Soi 38 to the south; the Central Lumpini section including Phloen Chit Road, Rama I Road, Soi Langsuan, Soi Sarasin, Chitlom Road Ratchadamri Road, Witthayu Road and Rachaprasong Road; the Silom / Sathorn section; and the Riverside section fronting the Chaophraya River along Charoenkrung Road and Charoennakorn Road, where several five-star hotels are located. The city area is convenient for businessmen, expatriates and tourists, because of its proximity to many office buildings, retailing and local attractions. Approximately 62% or nearly 209,600 condominium units are located in Suburban Bangkok. Within the Urban area, the Northern Fringe contains the most number of units, followed by the City and Southern Fringe areas because of proximity to the centre and mass transit connections.

5.2.2 Mass transit effect

Considerable mention has been made of the effects on demand and consequently supply of condominiums located close to mass transit lines. Figure 5.2 examines in more detail the effect on pricing of proximity to these lines.

Area / Distance (M.-FT)	0-200m (0-656')	201-500m (659'-1640')	501-1,000m (1643'-3280')	>1,000m >3280'	Average Selling Price/SQM. (Baht) Average Selling Price/SQFT. ($)
city area	***150,000 ($500/F^2)***	***120,000 ($400/F^2)***	***105,000 ($350/F^2)***	***-***	***125,000 approx. ($416/F^2)***
eastern Fringe	110,000	88,000	73,000	-	**90,000**
northern Fringe	84,000	76,000	48,000	44,000	**63,000**
southern Fringe	-	-	-	-	**-**
outer city - east	-	74,400	60,000	40,000	**58,000**
outer city - West	78,000	67,500	54,000	-	**66,500**
suburban Bangkok	-	-	45,150	37,000	**41,000**

Table5.2: The average selling price of condominium units by distance from BTS/MRT stations
Source: Department of Land, Colliers International Thailand Research

From Table 5.2, in all locations the closer the distance to mass transit lines the higher the price for condominium units. Even a distance of 500 meters can deter a buyer due to the walk involved in the Bangkok heat and taking a motorbike or taxi would seem prohibitively expensive in relation to the distance. It would appear that the difference of about 600 meters from mass transit between one condominium development and another translates into roughly a 50% price premium. Properties in the city area can command prices in the plus 150,000 Baht per square meters if located a couple of minutes' walk from a station.

5.2.3 Unit types

One bedroom units remain the favorite type for city condominiums. This is partly because the middle income segment of the market needs to live in the city not far from their work places and the trend has been for having fewer children and later. This has given rise to what was once referred to as DINKS (Double Income No Kids) or families with one or two children. In exchange for a convenient location, households are opting for smaller unit sizes in order to be affordable. LPN Development Plc. can design a 1 bedroom unit within just 28.5 Sq m. and other developers are moving in the same direction. Single people also often prefer 1 bedroom units to studios and investors are keen on these units for the rental market and capital gains. The focus now is on greater utilization of smaller space and new designs that give the apartment an appearance of being bigger.

ZONE	SIZE RANGE (SQ M)	AVERAGE SIZE (SQ M)
City Area	33.00 - 66.00	45.83
Eastern Fringe Area	32.00 - 43.00	37.00
Northern Fringe Area	28.50 - 48.00	33.66
Southern Fringe Area	N/A	N/A
Outer City – East	30.00 - 45.00	37.50
Outer City – West	34.00 - 45.00	39.17
Suburban Bangkok	28.50 - 50.00	33.60

Figure5.11: Size of 1 bedroom units of condominium projects launched in 2009
Source: Source: Department of Land, Colliers International Thailand Research

One bedroom units in the city area range from 33to 66 sq m and the average unit size is approximately 45.8 sq m which is considerably smaller than the average 1 bedroom unit size of 61.2 sq m in 2008. The reason is that most of those launched in 2008 were for luxury, grade-A condominiums while in 2009 the focus was on grade-B level. However the city area still contains larger units due to the number of luxury developments. The smallest units can be found in the suburban area due to affordability while the northern fringe comes a close second due to the same reason coupled with higher land prices.

Figure5.12: Example of Size of One Bedroom from LPN
Source: Source: Lumpini Ville Ladprao - Chokchai 4, 1 bedroom unit 28.5 Sq m. (285 Sqft.)

5.2.4 Forecast

Department of Land, Colliers International Thailand Research predicts that there are also some new developers planning new projects for the second half of 2012. Lower- to middle-income groups are still the main target market for developers who plan to launch new projects in the area outside mass transit lines or not far from the new mass transit extension stations. There are some listed developers still focusing on high net worth clients by scheduling the launch of new luxury condominium projects in the second half of 2012. Some listed developers are also focusing more on foreign buyers by arranging events or road shows in Singapore, Hong Kong and other countries in the region to promote direct sale of their projects. Thailand is located in the centre of Asia Pacific and has great potential for AEC in 2015.

Many foreign developers are entering Thailand by themselves or looking for joint ventures with Thai developers to start their first projects in the country. Many developers are focusing more on precast system because of the decrease in the labour force, the increase in minimum wage to THB300 per day in Bangkok and the opening of Myanmar. This has also caused the completion dates for some projects to be postponed.

Chapter 6

Setting the Benchmark

6.1 Setting Benchmark and Asian Green City Index

Benchmarking may be used as a helpful management tool in minimizing potential environmental impact. Benchmarking is the process of improving performance by identifying, understanding, adapting and implementing best practices and processes of both local and global policies. By using these pre-defined building performances, it is possible to document development trends and compare performance with similar activities or operations. This may contribute to systematic work towards improved environmental performances. Benchmarking is an invaluable tool for assisting in strategy development for high performance design. High rises that compare their performance against others and identify best practices are more able to gain strategic, operational and economic advantages by improving their practices and processes. This will also lead to higher levels of competitiveness. Benchmarking is likely to lead to rapid performance improvements, which would otherwise have taken longer to achieve.

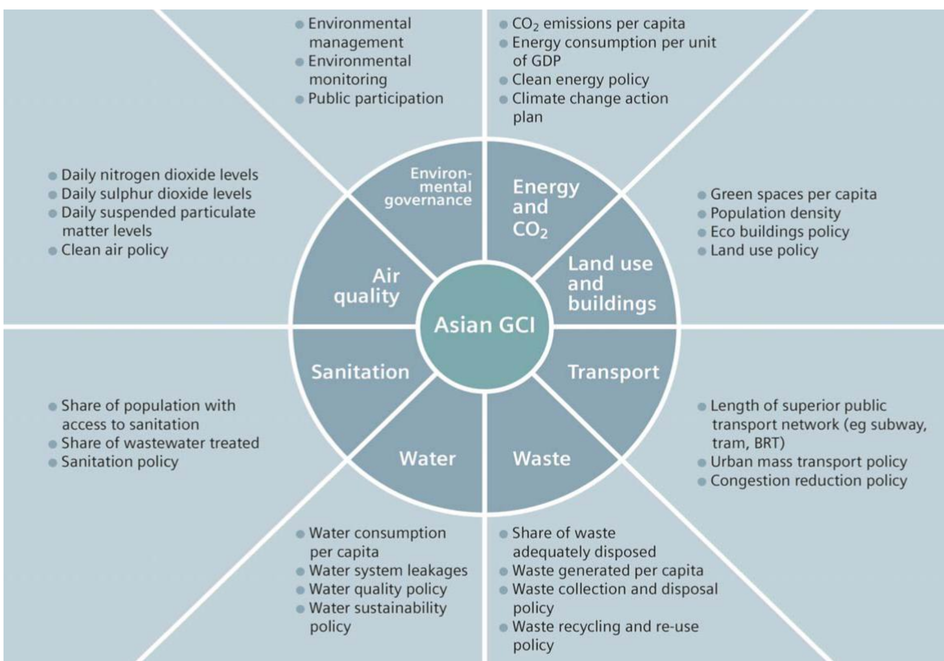

Figure 6.1: Unique index for Asian GCI
Source: Jan Friederich, Asian Green City Index, Economist Intelligence Unit, 2011

The Bangkok Metropolitan Administration (BMA) and Asian Green City Index (AGCI) provide assessments of environmental challenges to define energy performance guideline for both urban setting and building design. The benchmark is established to measure the model's proximity to the energy targets. We must consider how much energy is used and appropriate standards based on existing performances. The environmental performance analysis conducted on Asian's cities sets up the benchmark of building performance for sustainable consideration which can be used for both local and neighboring countries. This document is based on the Economist Intelligence Unit (EIU), which study Asian cities under the environmental awareness and climate protection guidelines.

The Asian Green City Index[1] examines the environmental performance of 22 major Asian cities in eight categories: energy and CO2, land use and buildings, transport, waste, water, sanitation, air quality and environmental governance (figure 6.1). The EIU developed the methodology in cooperation with leading urban experts around the world, including representatives of the OECD, the World Bank and Asia's regional network of local authorities. Bangkok is one of the Asian cities in this report, which will help to set up the energy's benchmark for both BMA and building performance design.

Total population (million)	5.7
Administrative area (km2)	1,568.7
GDP per person (current prices) (US$)	9,095.4[1e]
Population density (persons/km2)	3,607.4[e]
Temperature (24-hour average, annual) (°C)	28.0

Table 6.1: Background indicators in Bangkok, Data applies to Bangkok City,
1) Based on population for Bangkok Metropolitan Region, e) EIU estimate
Source: Asian Green City Index, the Economist Intelligence Unit, Siemens

Asian Green City Index describes Bangkok to be facing many environmental challenges including urban sprawl and insufficient infrastructure to deal with a growing population. According to the available data in the Index, Bangkok's indicators are taken from different locations. For example, indicators for green spaces and water consumption take into account

[1] Asian Green City Index, the Economist Intelligence Unit, Siemens, 2011

the metropolitan region, which has a population of about 12 million; while indicators for waste, transport and air are taken from the city centre, which has a population of about 5.7 million. Bangkok ranks average overall in the Index (figure 6.2). Its best performances are in the air quality and environmental governance categories, where it ranks above average. In the air quality category, Bangkok has below-average daily concentrations of the three pollutants measured in the Index, and the city has also made particular progress on vehicle emissions standards recently. The city scores well for environmental governance. It has a dedicated environmental department with a wide remit, which keep residents well informed and involved in the environmental decisions. The city's performance is below average in the categories of land use and buildings, transport, waste, water and sanitation. Particular weaknesses in these categories include a relative lack of green spaces, higher-than-average levels of waste generation and water consumption, and a low amount of treated wastewater.

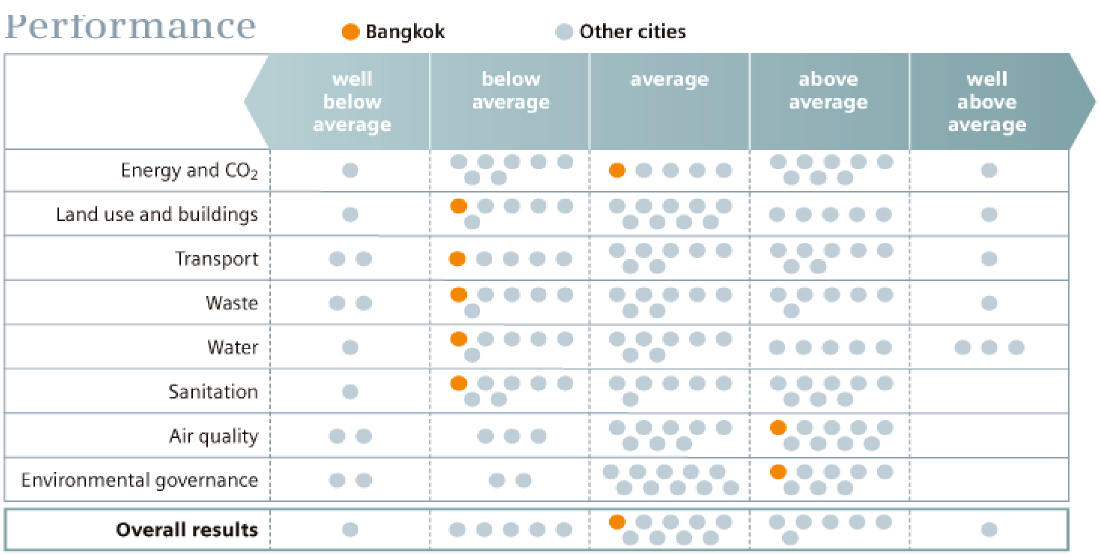

Figure 6.2: Bangkok performance
Source: Asian Green City Index, Economist Intelligence Unit 2011

This will show more information based on Asian GCI report which is divided into 8 performance categories[2];

- <u>Energy and CO2</u>

  Bangkok ranks average in energy and CO_2. Annual CO_2 emissions are an estimated 6.7 tonnes per person, above the 22 city average of 4.6 tonnes per person. The city's emissions levels are mainly due to high rates of car ownership and electricity

[2] Asian Green City Index, the Economist Intelligence Unit, Siemens, 2011

generation. According to the national Ministry of Energy, the transportation sector accounts for almost 40% of the city's CO_2 emissions. There are now more than 6 million vehicles registered in the city, up from around 4.2 million in 1999. Electricity generation used mainly for lighting and air conditioning, accounts for a further third of the city's CO_2 emissions. Only about 5% of electricity is generated through renewable sources, with most electricity coming from natural gas.

- Land use and buildings

  Bangkok ranks below average in the land use and buildings category, mainly for a relative lack of green spaces. At 3 square meters per person across the metropolitan area, Bangkok is well below the Index average of 39 square meters. Green spaces have suffered at the expense of rapid urbanization and a general tendency to favor economic development over environmental priorities. The city has the opportunity to bolster its eco-buildings policies, since it currently only has a partial code for eco-efficiency standards in new private buildings and has no green standards for its public buildings.

- Transport

  Bangkok ranks below average in the transport category. In recent years the city has expanded its mass transit network, which now incorporates a 23-km elevated rail network and a 20-km underground train network. Over the next two decades plans are in place to build several new lines and extensions of existing lines, raising the length by some 350 km. In spite of recent expansions, the length of Bangkok's superior public transport network (defined in the Index as transport that moves large numbers of passengers quickly in dedicated lanes, such as metro, bus rapid transit or trams) remains well below the Index average, at 0.04 km per square kilometer compared to the average of 0.17 km per square kilometer. In addition, the city does not have integrated pricing system for its public transport system. Traffic congestion also remains a serious problem throughout the city, since many residents choose to drive rather than take public transport.

- Waste

  In the waste category, Bangkok ranks below average, due mainly to the large of amount of waste the city produces and the relatively low percentage it collects and disposes of adequately. The city generates 535 kg per person, versus the Index average of 375 kg per person, and only collects 63% of it, versus the Index average of 83%. Much of

Bangkok's waste is disposed of in landfills after being transported to one of three sorting yards, but officials are concerned that landfill space is running out. There are plans in place to build an incinerator within the next decade. Although the city's approach to waste has suffered in the past because of a lack of initiatives to encourage residents to reduce waste and recycle, the city is marked up in the Index for having a waste strategy in place.

- Water

  Bangkok ranks below average in the water category. Its performance reflects the city's relatively high level of water consumption, at 340 liters per person per day, compared to the Index average of 278 liters. The high consumption rate is due in part to abundant water resources, with about 90% of the city's supply coming from treated water from the Chao Phraya and the Mae Klong rivers. The quality of river water is deteriorating from pollution, however, and intense groundwater pumping for the rest of the water supply has resulted in land subsidence and salinity contamination. Leakages in the water system are also a problem, with Bangkok losing around 35% of its water supply, compared to the 22-city average of 22%.

- Sanitation

  Bangkok ranks below average in the sanitation category. Only an estimated 51% of Bangkok's residents have access to sanitation, versus the index average of 70%. Bangkok also lacks adequate wastewater treatment facilities, and treats only an estimated 12% of wastewater, compared to the Index average of 60%. Indeed, most wastewater is discharged directly into the city's main river and canals, although there are plans in place to improve its treatment capacity city scores well on sanitation policies, and is marked up for its sanitation code, wastewater treatment standards, and regular monitoring of on-site treatment facilities in homes or communal areas.

- Air Quality

  Bangkok ranks above average in the air quality category. Average daily levels of the three pollutants measured in the Index —nitrogen dioxide, sulfur dioxide and particulate matter — are below the Index averages. However, air pollution from traffic congestion in the built-up parts of the city remains a challenge, and the city has made some strides to introduce incentives for cleaner vehicles.

- <u>Environmental governance</u>

  Bangkok ranks above average in the environmental governance category. The city performs well for having a dedicated environmental department and the capacity to implement its own environmental legislation. In the Bangkok Metropolitan Area, the Department of the Environment for the Bangkok Metropolitan Administration oversees and implements environmental policies. In addition the city has authority to change sections of national law according to local requirements. Officials also involve residents in decisions about projects with environmental impacts, and provide the public with access to online information. The city receives full marks in the Index for regularly monitoring its environmental performance and publishing information on progress.

Quantitative indicators: Bangkok

		Average	Bangkok*	Year**	Source
Energy and CO_2	CO_2 emissions per person (tonnes/person)	4.6	6.7 ^{1e}	2008	Metropolitan Electricity Authority; Department of Alternative Energy Development and Efficiency Annual Report 2008; IPCC; EIU estimates
	Energy consumption per US$ GDP (MJ/US$)	6.0	6.1 ^{2e}	2008	Metropolitan Electricity Authority; Department of Alternative Energy Development and Efficiency Annual Report 2008; EIU estimates
Land use and buildings	Population density (persons/km^2)	8,228.8	3,607.4 ^{e}	2008	Department of Provincial Administration
	Green spaces per person (m^2/person)	38.6	3.3 ^{3}	2007	Action Plan on Global Warming Mitigation 2007 - 2012
Transport	Superior public transport network , covering trams, light rail, subway and BRT (km/km^2)	0.17	0.04	2010	Bangkok Metro Public Company Ltd; Bangkok Mass Transit System Public Company Ltd; Bangkok BRT
Waste	Share of waste collected and adequately disposed (%)	82.8	62.9	2002	National Statistical Office of Thailand
	Waste generated per person (kg/person/year)	375.2	534.8	2005	National Statistical Office of Thailand
Water	Water consumption per person (litres per person per day)	277.6	340.2 ^{3}	2008	Metropolitan Waterworks Authority
	Water system leakages (%)	22.2	35.0 ^{4}	2003	Asian Development Bank
Sanitation	Population with access to sanitation (%)	70.1	51.0 ^{5e}	2003	United Nations Environment Programme
	Share of wastewater treated (%)	59.9	12.2 ^{6e}	2003	United Nations Environment Programme
Air quality	Daily nitrogen dioxide levels (ug/m^3)	46.7	42.7	2007	National Statistical Office of Thailand
	Daily sulphur dioxide levels (ug/m^3)	22.5	12.6	2007	National Statistical Office of Thailand
	Daily suspended particulate matter levels (ug/m^3)	107.8	48.1	2007	National Statistical Office of Thailand

Figure 6.3: Quantitative indicators of Bangkok in main 8 categories.
Source: Asian Green City Index, Economist Intelligence Unit 2011
* All data applies to Bangkok City unless stated otherwise below, ** Where data from different years were used only the year of the main indicator is listed, e) EIU estimate, 1) Electricity data only available for Bangkok Metropolitan Region, 2) Based on 2005 GDP estimate; electricity data only available for Bangkok Metropolitan Region, 3) Bangkok Metropolitan Region, 4) Non-revenue water, 5) Based on population covered by wastewater control plants, 6) Based on treatment area

6.2 Bangkok energy performance to Benchmark building design approach

Asian Green City Index provides quantitative and qualitative numbers which are able to target benchmark of building energy performance. These tangible numbers will be considered as part of the space and energy proportion. Setting the benchmark will provide pre-design or energy targets, which will in turn to set up the ultimate strategies to achieve the goals of the benchmark. The purpose of setting a benchmark is to reduce the energy demand and carbon emission from buildings through a multiple strategies, including consideration of zero energy sources in some energy consumption. Therefore, this benchmark will aim towards the Energy intensity in residential mixed use, water consumption, and green space. They all have major impacts on the prototype design of tall buildings. Transportation, environmental governance, and waste are also parts of the context and policy consideration, however, are not a part of the energy analysis.

6.2.1 Energy Intensity

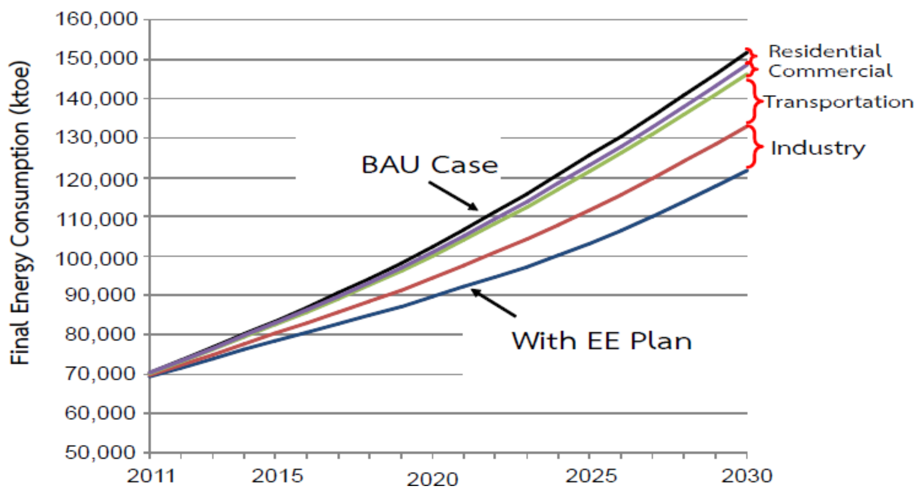

Figure 6.4: Energy Conservation Targets by Economic Sector
Source: Ministry of Energy, Thailand 20-Year Energy Efficiency Development Plan 2011-2030

Recently the Ministry of Energy Thailand has established the 20-year Energy Efficiency Development Plan (EEDP)[3] 2011-2030, which is designed to reduce the energy intensity by 25% before 2030 compared with the 2005 target for reduction of final energy consumption by 20% ~~in~~ before 2030, which is about 30,000 thousand tons of crude oil equivalent (ktoe). Large-scale energy businesses (e.g. those in the electricity, oil and natural gas industry) will be required to implement energy conservation promotion measures to encourage their customers to reduce energy use by a specified minimum standard (Energy Efficiency Resource Standards: EERS), instead of allowing such measures to be voluntarily undertaken as previously practiced.

Energy Conservation targets of EEDP was described in two major parts: first, economical use or reduced expendable use of energy; and second energy efficiency

[3] Ministry of Energy, Thailand 20-Year Energy Efficiency Development Plan 2011-2030

improvement, i.e. doing the same activities with less energy, involving, among others, lighting, hot water production, cooling systems, transportation or running machines in the manufacturing process.

The international consensus on energy conservation targets, i.e. the Joint Declaration of the Asia-Pacific Economic Cooperation (APEC) Leaders, is to reduce energy intensity (EI), or the amount of energy used per unit of GDP, by 25% before the year 2030. If Thailand is determined to achieve the 2030 energy conservation target, its final energy consumption by 2030 must be reduced by 20%, or about 30,000 ktoe. In the case where energy conservation measures can be successfully implemented up until the energy consumption by 2030 should only increase at an annual average rate of 3.0%, or an increase of only 1.7 times the current demand (Figure 6.4).

For the assessment of energy conservation potential in the large commercial building group, the energy consumed is divided into electricity and fuel. Electricity consumption in 2007 by eight major building types is shown in table 6.2

Building Type	Electricity Consumption (GWh)	Share (%)
Office building	7,139	37
Department store	2,351	12
Retail & wholesale business facility	2,351	12
Hotel	2,339	12
Condominium	1,303	7
Medical center	1,172	6
Educational institution	1,102	6
Other general buildings	1,365	8
Total	**19,125**	**100**

Table 6.2: Electricity Consumption in 2007 in the Large Commercial Building Group by Building Type
Source: Ministry of Energy, Thailand 20-Year Energy Efficiency Development Plan 2011-2030

The assessment of electricity saving potential is based on the comparison between the average energy consumption rate/space unit/year of individual building types at present, called the **"Reference Case,"** and in the case where the minimum energy consumption efficiency standard of buildings, or **"Building Energy Code (BEC),"** is enforced, including the case where a higher standard in the future is enforced. The average energy consumption rate under the Reference Case is derived from the energy consumption modeling representing each building type, based on the official data from energy consumption inspection. The parameters that are modified or changed to achieve greater energy efficiency of heat transmission include building envelope, air-conditioning efficiency, lighting and electrical equipment/appliance efficiency, and air ventilation.

Building Type	Energy Consumption under Each Level of Energy Saving Capability (kWh/m²/y)				
	Reference	BEC	HEPS	Econ	ZEB
Office building	219	171	141	82	57
Department store	308	231	194	146	112
Retail & wholesale business facility	370	298	266	161	126
Hotel	271	199	160	116	97
Condominium	256	211	198	132	95
Medical center	244	195	168	115	81
Educational institution	102	85	72	58	39
Other general buildings	182	134	110	66	53

Table 6.3: The net energy consumption derived from modeling each building type under each level of energy saving capability
Source: Ministry of Energy, Thailand 20-Year Energy Efficiency Development Plan 2011-2030

With regard to Energy efficiency standards which are higher than the BEC comprise the following three levels[4]:

- **HEPS (High Energy Performance Standard)** is the high energy efficiency standard of various systems which can be achievable by using current technologies.
- **Econ (Economic building)** is the target in the near future when the technologies of equipment and various systems are developed to be more energy efficient, but are still cost-effective.
- **ZEB (Zero Energy Building)** is the long-term target when the need for external energy supply to the buildings is near zero because the energy demand of such buildings is very low and there is also on-site energy generation from renewable energy.

[4] Ministry of Energy, Thailand 20-Year Energy Efficiency Development Plan 2011-2030

The EEDP reported that the net energy consumption derived from modeling each building type (Table 6.3) shows the potential of creating the energy benchmark for residential model types. Nevertheless, comparing the energy benchmark between the reference case and the ZEB case (observing about 1/3 – 1/4 difference) infers that on site renewable energy must be maximized and energy demand must be minimized for new building construction. Realistically, EED's energy estimation for the ZEB case is very optimistic and is, most likely, unachievable. This thesis will investigate optimal scenarios that are both achievable and feasible. Therefore, the capacity range from the HEPS case to the ZEB case (from 198 kWh/m^2/year to 95 kWh/m^2/year respectively) will be used for considering the energy benchmark.

- Approach of Energy Benchmark of Residential building according to EEDP is about **200 kWh/m^2/year**
- Approach of Energy Benchmark of Retail*s* according to EEDP i**s 370 KWh/^{m2}/Year**

6.2.2 Water Conservation

Asian Green City Index shows data from Metropolitan Waterworks Administration (MWA), Bangkok residents use water 340 liters per capita per day (986 lbs/capita/day), where leakages account for about 35%, which is lower than the average in comparison to other Asian cities. In setting up a benchmark for water consumption, leakage is not part of the consideration because it is a BMA and MWA policy and implementation. My research will be based on the stand alone building and holistic idea of urbanistic perspective in term of reducing carbon emission and conservation. However, in designing high performance tall buildings in metropolitan area, water is the most significant resource that usually has a low renewability prospect because of impervious surfaces in the urban area which also increases temperature levels. Tall building design can consider water conservation by collecting water during the rainy season (May - October). Unfortunately, as figure 4.9 in chapter 4 indicates, very little water can be collected for the year because the duration for the rainy season is short. Bangkok has a high average amount of rainfall, which could be used to set up the benchmark for water conservation.

Rule of thumb for rainwater captures calculation:

0.52 X Roof Area (sq.ft) X Rainfall (inch per year) = Gallons per Year[5]

From designed proposal in Chapter 7 ;

In calculation; ***0.52 x 22,966.70 ft² x 55" per year =656,847.62 gallons / year***

(1,642.12 gallons/person/year or 4.5 gallons / person/day)

The benchmark aims to conserve water by collecting 5% of the amount typically used. If the typical use is about 340 liters/capita/day, the target water collection would be 17 liters/capita/ day (4.5 gallons / person/day), which is lower than average in the Asian Green City Index (277.6 liters/capita/ day)[6]. The rainfall benchmark is for the entire year in a residential building with a 400 occupancy load. The total rainfall that will be collected is 1,642.12 gallons/ 400 person/ day from an approximate roof area of about 22,966.70 sqft (see chapter 7). The benchmark for the amount of rainfall collected does not include water conserved from pervious surfaces. Thus, it will not be considered for our calculation of water conservation. The water from impervious surfaces will be used for landscaping irrigation only.

6.2.3 Green space

According to the Asian Green City Index reported from Action Plan on Global Warming in 2007 – 2012, Bangkok ranks below average in the land use and buildings category, mainly for a relative lack of green spaces. At 3 square meters per person across the metropolitan area, Bangkok is well below the Index average of 39 square meters. To build green spaces up to Asian GCI average is quite difficult, considering that the space in Bangkok Metropolitan has a very high density of population. Benchmark of green space applied to land use in Bangkok, especially in Sukhumvit area have a 1:10 FAR, which allows for more residential space and open space. The best benchmark for the initial tall buildings design should provide at least 3 square meters per person with open space, not including personal units.

[5] Courtesy of Ed Haemmerle from NJ Renewable Energy, http://rainwaterhog.com/
[6] Asian Green City Index, Economist Intelligence Unit 2011

By the state law, site area requires an OSR (Open Space Ratio)[7] of 3% of total floor area, in addition to 50% of open space that must be used use for landscaping. Thus, compared to state law for OSR, the high rise residential benchmark will provide for more open space. The benchmark for open space and personal green space will improve air quality into the interior environment and also reduce heat storage form UHIs. The proposed open space area from Chapter 7 is about 33,270 sqft which sets the target to 10% of total floor area providing green space of at least 80 sqft per person in addition to the vertical green wall.

6.2.4 Parking space

Chapter 5 defines the grading of condominium type including the amount of parking stalls. Personal vehicles in Bangkok are increasing rapidly. In order to reduce carbon emission and heat island, minimizing fuel demands is needed. The benchmark for parking space is approximately 70,000 sqft, including ramp and circulation, which will provide 174 stalls for the 400 units, accounting for 50% of total units.

Transport Mode	Energy per Transport Unit [8] (MJ/ton-km)	Share of Transport Mode Current[14,15]	Share of Transport Mode In 2030* (Base Case)	Share of Transport Mode In 2030** (Target)	Energy Saving Potential (ktoe)
Land	2.5	87.5%	85.0%	73.2%	2,422
Rail	0.75	2.6%	5.2%	17.0%	
Waterway	0.25	9.8%	9.8%	9.8%	

Table 6.4: Energy Conservation Potential as a Result of Goods Transport Mode Shift
Source: Ministry of Energy, Thailand 20-Year Energy Efficiency Development Plan 2011-2030

The total energy saving potential derived from the travel and goods transport mode shift ~~is~~ of 2,770 ktoe can potentially be achieved from the decrease use of private vehicles to the increase use of public transport systems (2,422 ktoe) as shown in table 6.4, and to infrastructure development (348 ktoe).

[7] Architect Siam Association (ASA), Law and regulation

There are three energy scales presented in Table 6.2: the urban planning scale (Asian GCI), building scale based on BMA and EEDP research which follows a summary of approaching benchmark.

Category	Existing Performance	Benchmark Approach
Energy Intensity electricity for Residential (Based on EEDP)[8]	256 KWh/m^2/Year	HEPs (High Performance Standard) **about 200 kWh/m^2/year**
Retails[9]	370 KWh/m^2/Year	HEPs (High Performance Standard) **266 kWh/m^2/year**
Water consumption[10]	89.81 gallons/capita/ day	Capture 5% of total used, **4.5 gallons /capita/ day** during 12 months
Green Space (Based on Asian Green City Index), ASA, Law and Regulation	30 sqft./ person OSR[11] require 3% of total floor area	**Open Space and Green space 10% (70-80 sqft/ person)**
Parking space	60 – 80% for condominium grade B[12]	**50% parking stalls**

Table 6.5: Summary of Benchmark approaches to High-Rise Residential Mixed use building.

[8] Ministry of Energy, Thailand 20-Year Energy Efficiency Development Plan 2011-2030

[9] Ministry of Energy, Thailand 20-Year Energy Efficiency Development Plan 2011-2030

[10] Asian Green City Index, Economist Intelligence Unit 2011

[11] Architect Siam Association (ASA), Law and regulation

[12] Colliers International Thailand scrutinizes every condominium project in Bangkok and provides a grade based on the criteria table 5.1

Chapter 7

Prototype Design Configuration

The proper balance between energy demand and renewable energy supply maximizes the potential for building performance and design. The key strategy to achieve such symbiosis in this thesis is to lower energy demand without sacrificing human comfort. Passive cooling design strategy is achieved by finding a prototype that enhances both natural ventilation and solar energy. A significant aspect in both strategies is the search for the baseline model that optimizes the use of passive energy. The investigation begins with an array of proposed building geometries that are oriented for maximum building ventilation. The thesis will also evaluate thermal comfort to define how the internal environment of these geometries performs. The main focus for this chapter will be to investigate the significant building components to support design.

7.1 Ideal building geometry

Building geometry is essential to any simulation of building performance. This paper examines the importance of building geometry in the simulation of energy performance which takes solar energy and a natural wind driven forces into account. Defining the ideal building geometry lies in the interoperability of building form and external environment condition. The most common case is simplification of building geometry that relevant to the simulation. “A building envelope is the separation between the interior and the exterior environments of a building. It serves as the outer shell to protect the indoor environment as well as to facilitate its climate control.”[1] Interior wall, interior windows, and other internal components are not to consider in this initial study.

7.1.1 Solar insolation study

Passive cooling design is a technique that avoids the heat of the sun to increase a building envelope’s temperature. The successful use of sun-path diagram (figure 7.2) depends upon both the correct understanding of the sun's movements and the best use of solar insolation in order to capitalize on the solar energy. Solar insolation is a measure of solar radiation energy received on a given surface area in a given time or period of time. Some of the solar radiation will be

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[1] The Centre for Sustainable Buildings and Construction, Building and Construction Authority, Singapore, page 41

absorbed, while the remainder will be reflected. Usually the absorbed solar radiation is converted to thermal energy, causing an increasing in the object's temperature.

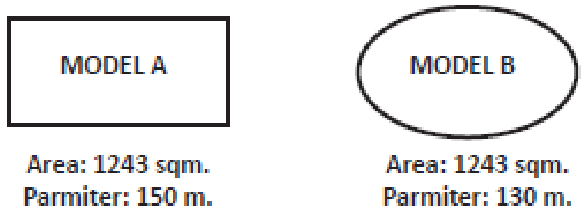


Figure 7.1: Initial building geometry forms

Some systems, however, may store or convert a portion of the solar energy into another form of energy, as in the case of photovoltaics or plants. The amount of insolation received at the surface of the building is controlled by the angle of the sun, the state of the atmosphere, altitude, and geographic location. This thesis will consider the insolation of two basic shapes; a rectilinear form and an ellipse form within the same floor plate area (figure 7.1)

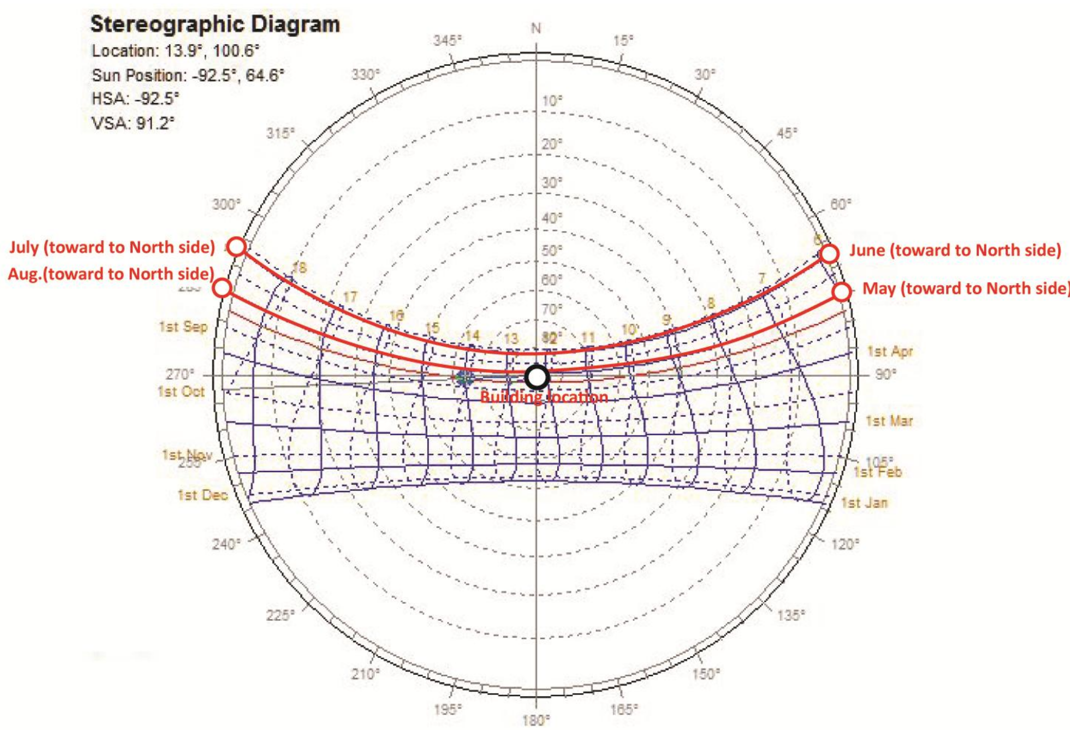
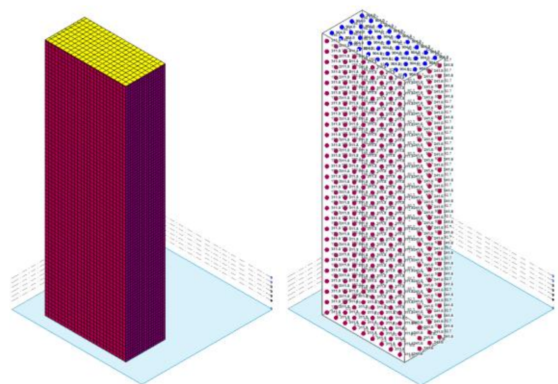
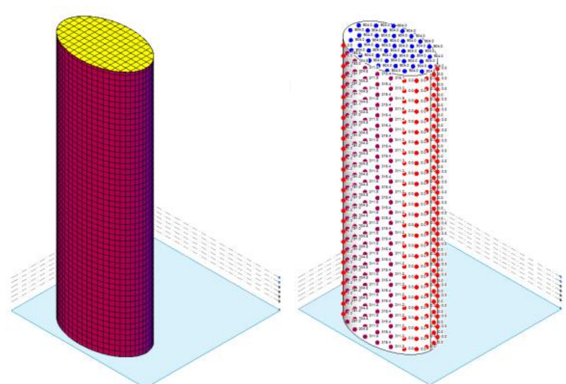


Figure 7.2: Sun-path diagram for Bangkok, Thailand
Source: EcoTect

Sun-path diagrams are used for the understanding of the sun's movements. The diagrams are representations on a flat surface of the sun's path across the sky. They are used to easily and quickly determine the location of the sun at any time of the day and at any time of the year. The examination direct solar rays at 9am, 12pm and 2pm during four different months: the hottest month (April), when the sun is due North (June), the rainiest month (September), and the coldest month (December). These months represent extreme conditions of the year and will play a large role in solar heat gain on all building facades. In order to determine the optimum building parameter and geometry that minimizes solar heat gain that transfers to the building, Project Vasari[2] is used to analyze the amount of solar radiation hitting the building surface of two ideal geometries.



Model A - Solar radiation study Model A - Solar radiation calculation node



Model B - Solar radiation study Model B - Solar radiation calculation node

Figure 7.3: Compare Solar radiation study on Model A and B
Resource: Project Vasari simulation

[2] http://autodeskvasari.com

Figure 7.3 shows a comparison of the solar radiation study between two ideal building models; Model A (Rectilinear geometry) and Model B (Ellipse geometry). Both of the ideal building geometries are assigned the same floor plate area with the perimeter of Model A of 150 meters larger than the perimeter of Model B of 130 meters. Obviously, there is a correlation between the building perimeter and solar radiation. The total amount of accumulated solar radiation hitting the selected surface of Model A is 49,7327.90 kWh/m^2 /year; a value higher than that of Model B of 40,7351.60 kWh/m^2/year. With the consideration to the minimum solar heat gain on the ideal building geometry, Model B has a potential to become a baseline ideal building geometry to take for further and deeper analysis.

7.1.2 Wind pressure and velocity streamline

Air will move only when it is pushed, pulled, heated up or cooled down. In a passive design, the heating and cooling can be done by solar radiation, whilst the pushing and pulling has to be done by prevailing wind. The building form determines the relative strength of these natural forces. This basically comes down to the ability of building to capture or funnel prevailing breezes. The building form can be designed to enhance ventilation. The wind-induced pressure of a building is a complex. In general, the pressure is positive on the windward side of the building and negative on the roof and the leeward façade. When the wind meets an obstruction, such as a building, it is deflected; and due to its momentum, creates positive and negative pressures over the surface of the building (RIBA, 2011)

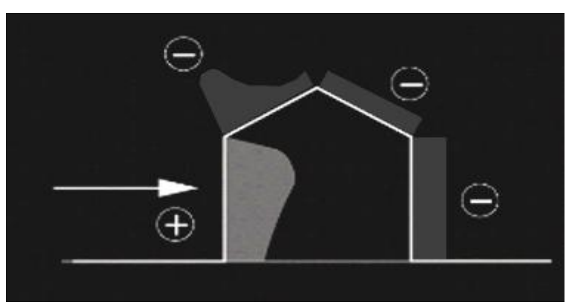


Figure 7.4: Wind pressure diagram

Bernoulli's Principle states that as the speed of a moving fluid increases, the pressure within the fluid decreases. Bernoulli’s principle describes a fluid flowing horizontally, the highest speed occurs where the pressure is lowest, and the lowest speed occurs where the pressure is highest (Babinsky, Holger November, 2003).

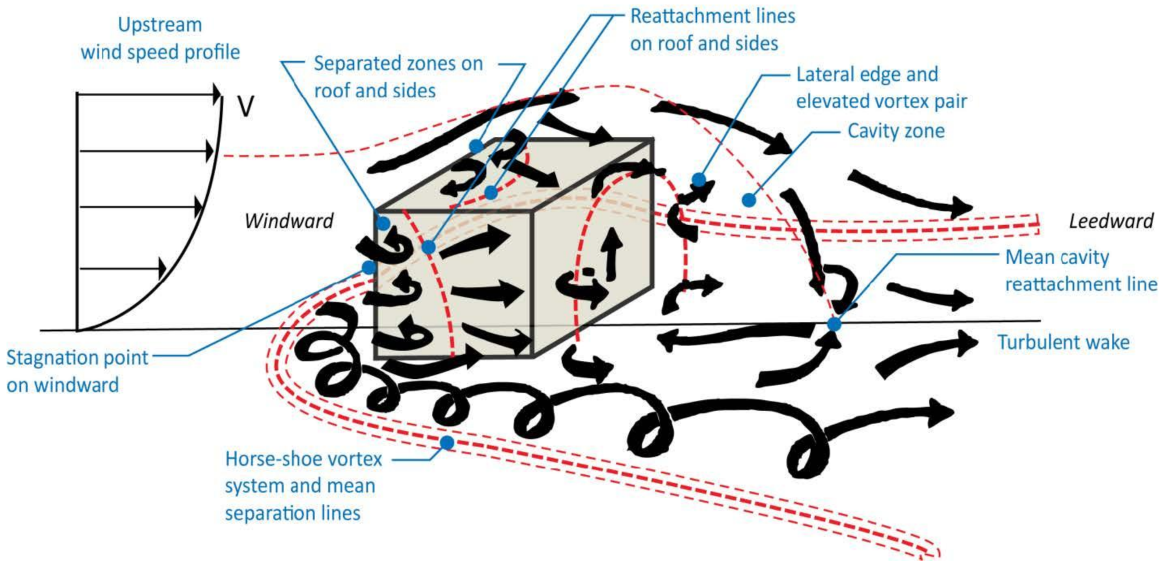


Figure 7.5: Schematic representation of the mean atmospheric boundary layer flow around an isolated sharp-edged low-rise building
Resource: Modified from Blocken, 2011)[3]

Figure 7.5 uses Bernoulli's principle to understand the nature of wind flow around a building. This schematic wind flow will influence the study of both two ideal building Model A and B to find the optimum wind flow potential on the external environment. *The schematic wind flow pattern* (Rayford P. Hosker, 1984) on windward building façade created maximum pressure at the stagnation point. Then the wind flow is deviated to the lower pressure zones of the facade: upwards, downwards and sideward. The upward and sideward flow separate at the upwind facade edges, and create a separation bubble or recirculation zone characterized by low velocity and high turbulence intensity. Building dimensions and turbulence of the oncoming flow are separated flow that can reattach to the side facades and roof (as illustrated in figure 7.5 by the dotted reattachment lines). A considerable amount of air flows downwards from the stagnation point and produces a vortex at ground level known as the standing vortex, frontal vortex or horseshoe vortex. This vortex characterizes the three-dimensional separation of the flow along a flat wall with a cylindrical obstacle. The main flow direction of the standing vortex near ground level is opposite to the direction of the flow that approaches the building. Where both flows meet, a stagnation point with low wind speed values exists at ground level, upstream

[3] Journal of Building Performance Simulation, 2011

of the building. The standing vortex stretches out sideways and sweeps around the building corners creating corner streams with high wind speeds.

At the leeward side of the building, an underpressure zone exists. As a result, backflow or recirculation flow occurs in a cavity zone that consists of vortices with horizontal and vertical axes (i.e. the near wake). The mean cavity reattachment line that is perpendicular to the building marks the end of the cavity zone. Beyond this location, the flow resumes its normal direction but wind speed stays slow for a considerable distance behind the building (i.e. the far wake). It is important to note that Figure 7.5 only shows the mean wind-flow pattern for a single building. In multi-building configurations, the flow patterns can interact, yielding a higher complexity. In the application of Bernoulli’s principle and the schematic wind flow pattern to both Model A and Model B, this thesis aims to define the optimum wind flow from the external environment; and to address the potential ventilation through internal environment based on the different building geometers. Figure 7.6 shows a comparative analysis of wind flow and streamline patterns on the different ideal building geometries using Star CCM+ CD-Adapco, an advanced Computational Fluid Dynamic (CFD) software to simulate win pressure and velocity streamline.

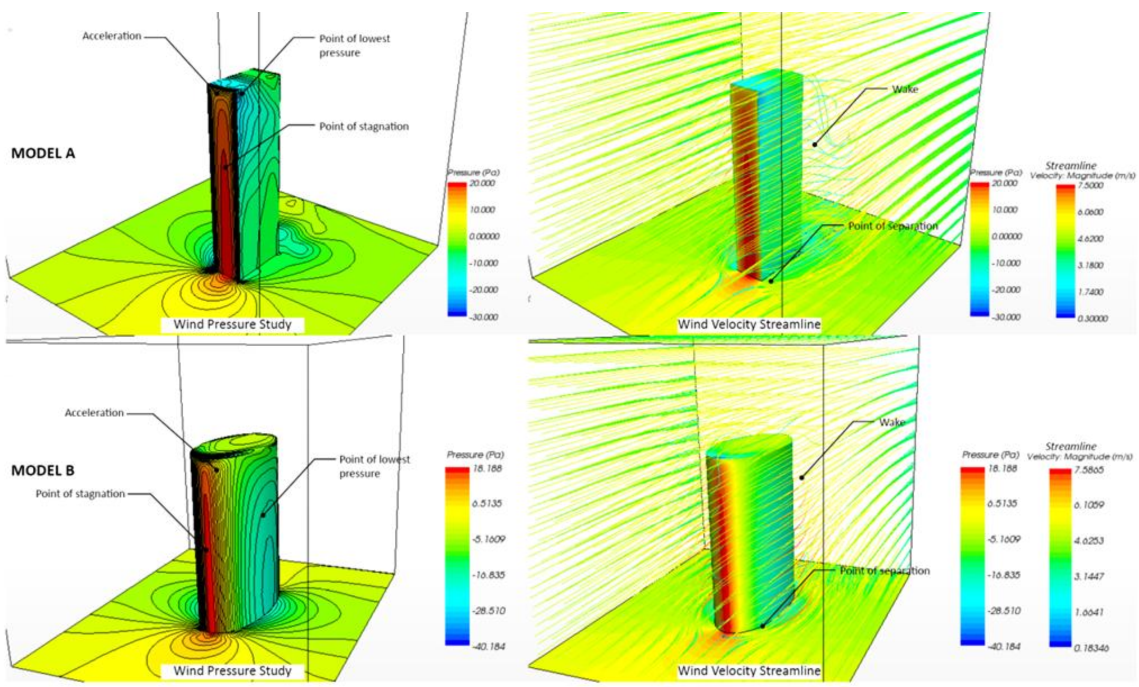


Figure 7.6: Comparative Wind flow and streamline pattern on different ideal building geometries
Resource: CD-Adapco , Star CCM+ CFD simulation

The building comparative study using CFD (Computational Fluid Dynamics) in figure 7.6 revealed some general characteristics about fluid flow velocity streamlines and wind pressure. Broadly speaking, the streamlines indicate that pressures are higher on the windward side of the building and lower on the leeward side and on the roof and so will tend to drive a flow within the building from the windward vents to the leeward vents. Typically, the fluid pattern creates a maximum wind pressure on the building façade at the point of stagnation from the windward side. The following terms explain the nature of fluid flow:

Point of stagnation:

The particle on the streamline impinges on the object surface and stalls. This result is a higher pressure on the surface at or close to the point of stagnation than in the bulk of the fluid.

Acceleration:

After stalling the particle accelerate away from the point of stagnation towards the sides of objects. This results in a reduction of the pressure.

Point of lowest pressure:

The particle has accelerated to the highest velocity along its path around the object and therefore the pressure is reduced. After this point the particle decelerates resulting in an increment in pressure.

Point of separation:

As the particle moves along the surface it loses energy due dissipation of energy to the bulk of the fluid and decelerates. At a point the viscous (turbulent) boundary layer separates from the surface and develops a downstream wake The particles move outwards into the fluids leaving room for a wake (e.g. areas filled with turbulent eddies)

Wake :

The area is filled with turbulent eddies that consume some of the flow energy. The pressure is lower in the wake than in the bulk of the fluid flow.

Figure 7.7 show the location and dimension of stagnation area and high wind pressure in both rectilinear and ellipse building geometries. The fluid streamline has been traced about mid building height at 75 meter (246 feet). The fluid pattern which began at the stagnation point (area of highest pressure) is reduced in pressure by the obstruction. A separation line occurs as the fluid pattern changes from high pressure to low pressure. The fluid streamline reacts differently to both building geometries, thereby, providing an opportunity to define an optimum wind pressure distribution pattern.

A comparison of the buildings revealed that the rectilinear building has the lowest pressure points due to more obstruction on the rectilinear building surface compared to ellipse building. Less obstruction means that flow is able to travel faster around the ellipse building, which allows for more wind-to-surface contact before the separation line occurs. A clear understanding of the external wind conditions allows designers to confidently predict air movement patterns within the building where the differences in wind pressure can play a key role.

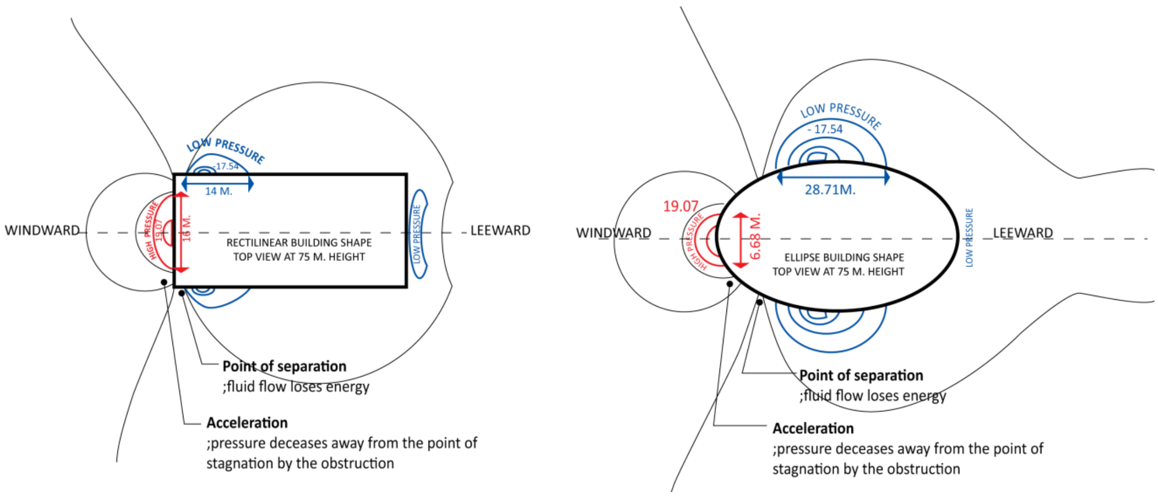


Figure 7.7: Comparative high and low pressure area on both building geometries

The comparison study in figure 7.8 reveals high pressure zones (red contour lines), as well as low pressure zones (blue contour lines) for both buildings. The high pressure areas provide an opportunity on the windward side for air intake; while the low pressure areas provide an opportunity for air outtake. The interplay between these two areas is important for optimum internal ventilation. The nature of fluid streamline plays a crucial role in the design for natural ventilation, as well as HVAC systems. Since wind pressure on building façade is not constant (with higher pressure and velocity at the higher floor levels), location of air inlets and outlets becomes a priority for air quality.

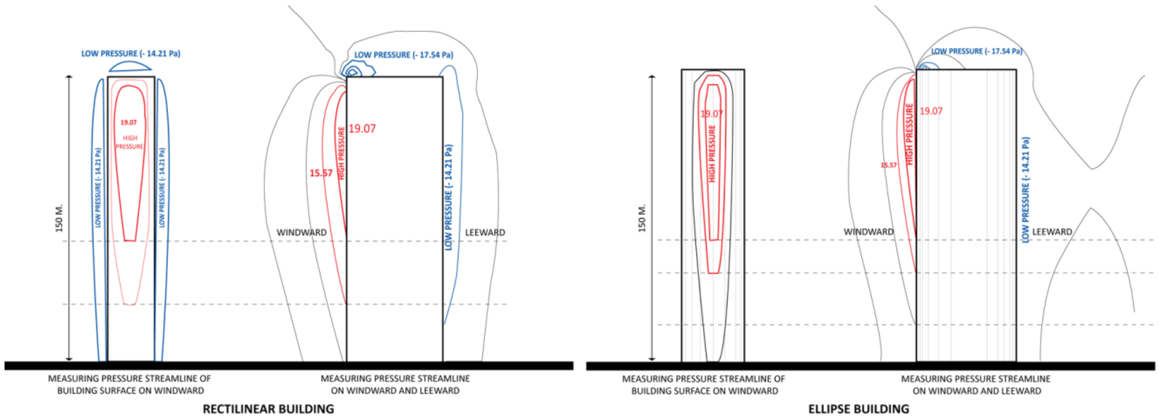


Figure 7.8: Comparative high and low pressure area on both building façade

Natural ventilation of buildings is the flow generated by temperature differences and by the wind. The governing feature of this flow is the exchange between an interior space and the external ambient. Although the wind may often appear to be the dominant driving mechanism, in many circumstances temperature variations play a controlling feature on the ventilation since the directional buoyancy force has a large influence on the flow patterns within the space and on the nature of the exchange with the outside. Both strategies work on the principle of air movement from a high to low pressure zones.

The fundamental approach for natural ventilation is effective cross ventilation, which uses air-pressure differentials caused by wind flow. The use of the wind potential for passive cooling of buildings makes it necessary to understand the physical phenomenon and the factors that influence the natural ventilation process. External variables such as local wind characteristics and the surrounding built environment; and internal factors such as the sizes, locations and characteristics of openings plays a key role in natural ventilation. As the wind passes through the building, it creates a pressure distribution around its facades. This pressure distribution is essential to natural ventilation process as it creates zones of high and low pressures on different sides of the building. The pressure differences induce the air movement into the building. Therefore, natural ventilation is essentially dependent on the pressure coefficient on the building's facades.

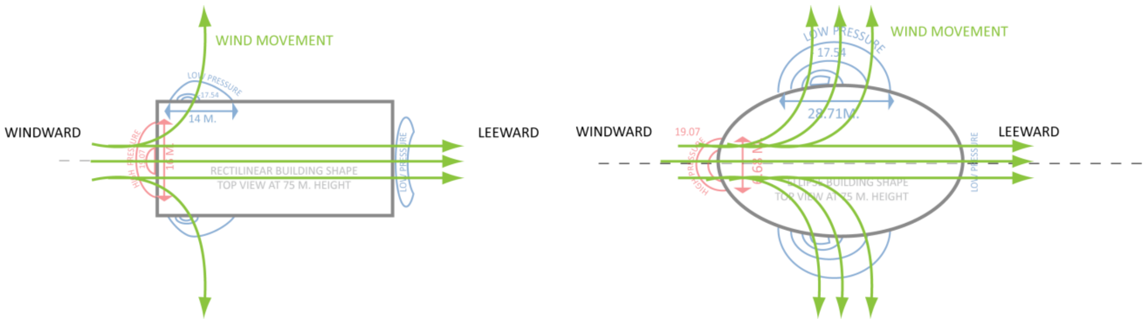


Figure 7.9: Wind movement opportunity on rectilinear (left) and ellipse (right) building.

A comparative study in both building geometries (figure 7.9) reveals different opportunities of wind movement from the external to the internal environment that are due to pressure differentials. The wind movement diagram shows that the ellipse shape is able to generate an optimum natural ventilation of internal space compared to the rectilinear shape. The lower pressure areas of the ellipse are along the side of the building envelope and have more wind-to-surface contact when compared to the rectilinear shape. On the other hand, the lower pressure areas of the rectilinear shape are located much closer to the windward high pressure area. Thus, the rectilinear shape produces a less desirable wind movement pattern when compared to the ellipse building shape. Nevertheless, the ***ellipse building shape (Model B)*** is producing the better opportunity for fluid flow. There are other factors to be considered in natural ventilation such as interior space layout, size and ratio of intake and outtake, and pressure moment. The focus of this research is to reveal conceptual fluid streamlines that are essential to building design and strategy.

7.2 Ideal urban setting and integrated study

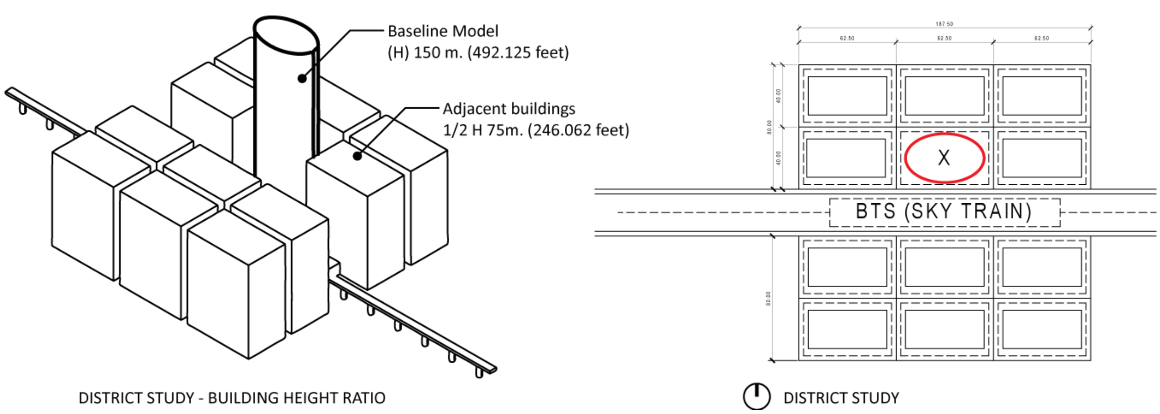


Figure 7.10: Axonometric model of district study and building height ratio (left) and layout (right)

The effect of wind on a building is dominated by the shape of the building and the proximity of other buildings. In this section, the attention is focused on how these pressure differences vary with building shape, building direction, and the presence of nearby buildings. Because separation is a major factor in determining the wind flow around the building, particularly downstream of the windward face, and most buildings have sharp corners, wind speed plays only a minor part in determining the air flow pattern around the building. The urban growth model analysis from chapter 5 (figure 5.6) presents the worst case scenario for a high-rise development in an urban district. Since the ellipse building geometry has the most advantages in terms of minimal solar insolation and wind flow pattern, Model B is chosen for further analysis in an urban setting. The site and its urban context is shown in figure 7.10. The proposed building will be the tallest with a height of 150 meters (500 feet). The surrounding buildings will half the size of the prototype with the height of 75 meters (250 feet). A sky train or elevated rail is located between the two major district blocks.

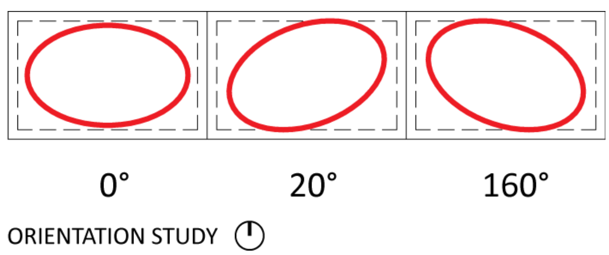


Figure 7.11: Orientation Study

Applying solar and wind studies to an urban context places much emphasis in building orientation. Figure 7.11 diagrams an orientation study for the ellipse building at three different rotation degrees: 0 degree, 20 degrees and 160 degrees. All three scenarios fit within building boundaries and setbacks.

7.2.1 Solar Insolation study

Natural ventilation of buildings is the flow generated by temperature differences and by the wind. The governing feature of this flow is the exchange between an interior space and the external ambient. Although the wind may often appear to be the dominant driving mechanism, in many circumstances temperature variations play a controlling feature on the ventilation since the directional buoyancy force has a large influence on the flow patterns within the space and on the nature of the exchange with the outside.

The diagram (figure 7.12) below demonstrates a comparative study of incident solar radiation on the ellipse building surface in three building orientations (figure 7.11). The incident relative number merely represents the total amount of cumulative solar radiation hitting the building surface that was generated by Project Vasari. The solar radiation analysis enables the study of incident solar radiation on a building form within the conceptual massing of the urban environment. This diagram visualizes the distribution of solar radiation on various areas of a mass by taking into account the shading effects from surrounding buildings in the urban setting. The purpose of this study is to analyze the effects of shading and seasonal impacts on the solar gain of a building. Also, it will quantify the difference between the incidents of solar radiation that occurs on the lower floors compared to the higher levels. This is especially significant in an urban context. The analytical results of this study are not meant to size photovoltaic panels; nor will it address how much solar heat gain is transmitted into the building.

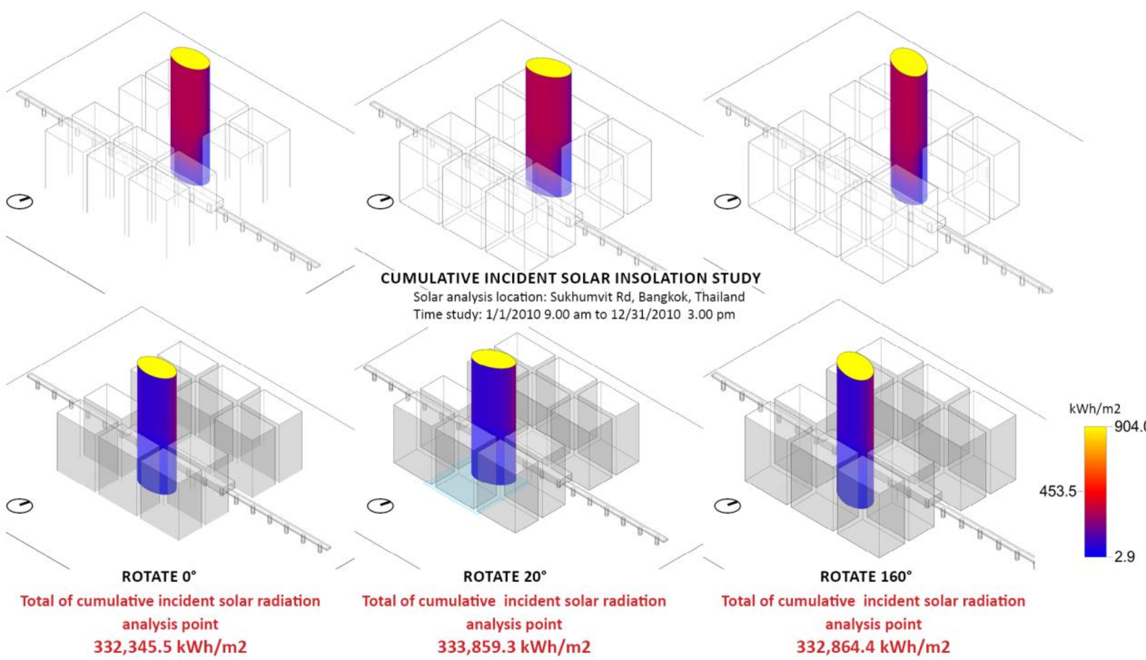


Figure 7.12: Comparative of Incident solar insolation study
Resource: Project Vasari simulation

7.2.2 Wind pressure coefficient and velocity streamline study

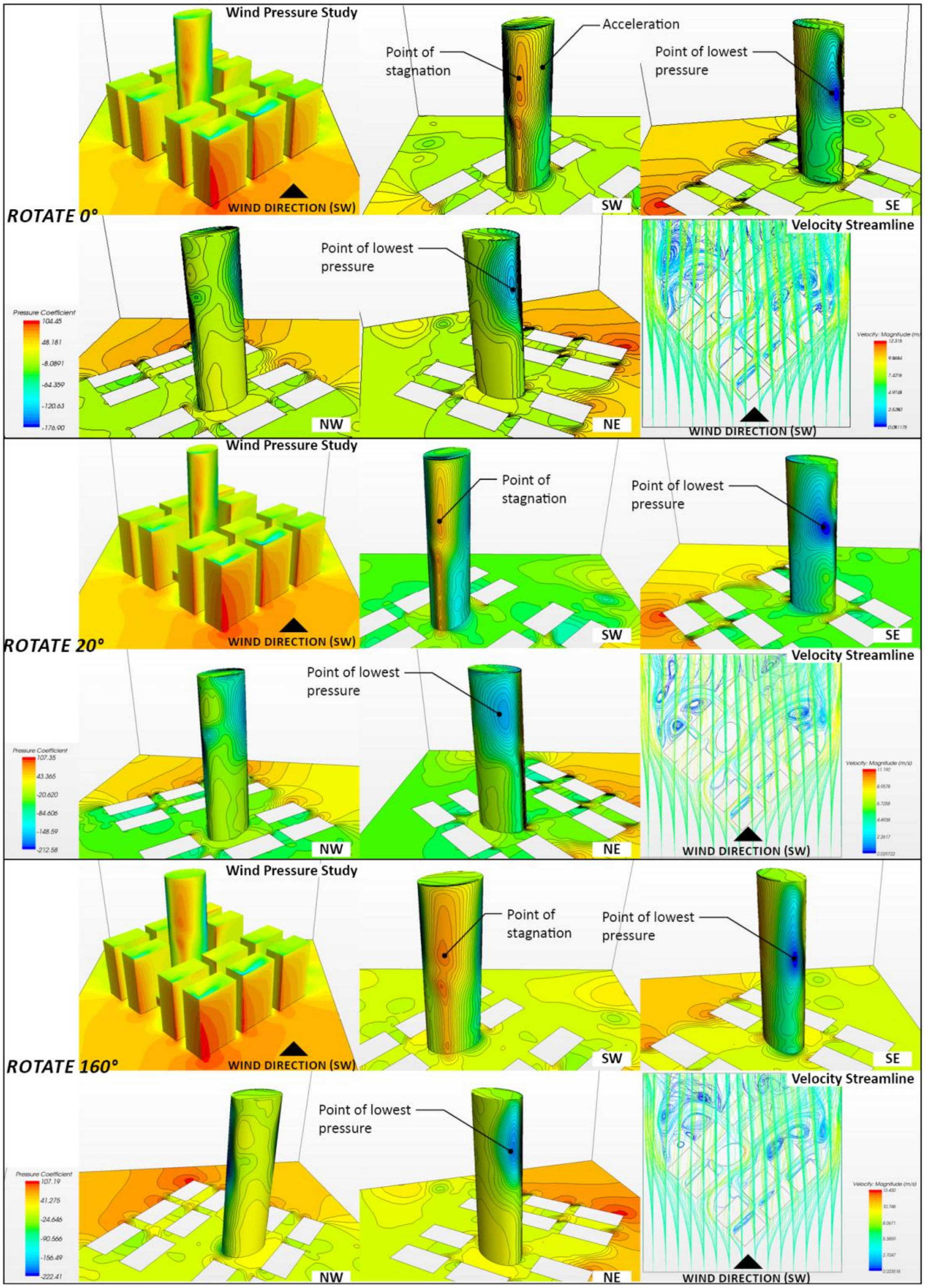


Figure 7.13: Comparative of wind pressure coefficient and velocity study differs by orientation
Resource: CD-Adapco , Star CCM+ CFD simulation

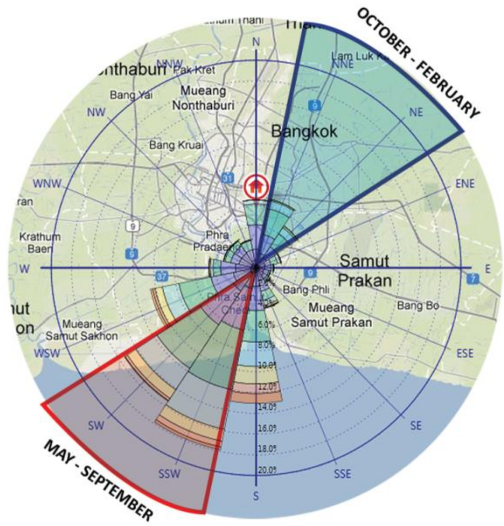


Figure 7.14: Wind rose: Two seasonal predominant wind directions from south-west and north-east

Difference in wind pressure is the key factor of wind movement for both external and internal environmental conditions. Wind force always travels from areas of high pressure, such as stagnation points where wind flow hits the building façade, to lower pressure. The comparative wind study in figure 7.13 attempts to define some certain baseline for optimal building orientation. The study was centered on wind-driven flows. Models of buildings are examined in an airstream and the pressure distributions around the building are measured for various orientations of the incident wind. Pressure coefficients are determined and these are used to calculate the flow through vents at different locations on the facade. Wind pressure on the building envelope, usually expressed by pressure coefficients (Cp)[4], are influenced by a wide range of parameters, including building geometry, facade detailing, position on the facade, the degree of exposure/sheltering, wind speed and wind direction. It is an important driving force for infiltration and ventilation.

The study demonstrates three major building orientations (0 degree, 20 degrees, and 160 degrees) within the context boundary. By using advanced computational fluid dynamic (CFD) simulation software, Star CCM+ defines the pressure coefficient on building façades of all three building orientations. Understanding the pressure coefficients can help locate intake and outtake vents.

[4] D. Costola, 2009

7.2.3 Thermal comfort study on different orientation

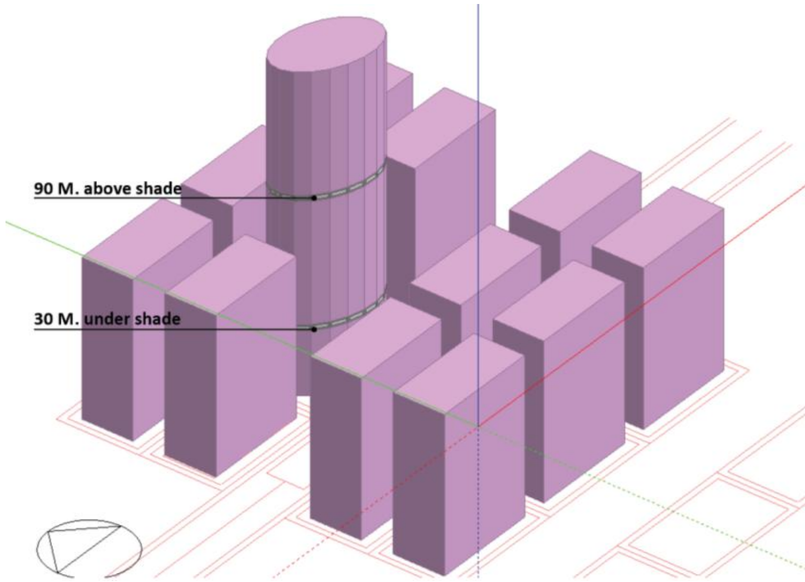


Figure 7.15: Comparative of wind pressure coefficient and velocity study differs by orientation
Resource: Designbuilding visualization

Solar insolation and wind pressure has different effects on building orientation. This session will identify the optimum building position for human comfort in the internal environment. Figure 7.15 is a thermal comfort model from DesignBuilder[5] to define the level of comfort hour, relative humidity, operative temperature, and PMV (Predicted Mean Vote). The thermal comfort study focused on two floor levels, 30 meters (100 feet) and 90 meters (200 feet), with the lower level surrounded by buildings and the higher level towering over the adjacent buildings. The thermal simulation was calculated throughout the entire year to observe comfort changes in the three building orientations. The thermal comfort calculation in table 7.1 shows a small difference in relative humidity, discomfort hour, and PMV. The difference in comfort level was not enough to distinguish an optimal building orientation. The geometry of building, ellipse or oval shape, may create a gradient energy transfer into the building. Natural ventilation in Bangkok has relatively low wind speed throughout the year.

[5] Whole building simulation application, http://www.designbuilder.co.uk/

Comfort Study at 30 meter
1 Jan. - 31 Dec. Monthly

0 degree

Month	2002	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air Temperature (°C)	28.50	29.07	30.27	31.21	30.67	30.52	29.90	29.17	29.33	29.57	29.39	27.95
Radiant Temperature (°C)	29.27	29.86	30.95	31.79	31.21	31.06	30.41	29.62	29.80	30.08	30.13	28.71
Operative Temperature (°C)	28.88	29.47	30.61	31.50	30.94	30.79	30.16	29.39	29.56	29.82	29.76	28.33
Outside Dry-Bulb Temperature (°C)	26.86	28.01	29.32	30.61	29.95	29.70	29.02	28.33	28.24	28.00	27.73	26.39
Relative Humidity (%)	63.06	63.58	66.48	66.42	68.74	73.29	69.29	72.33	72.44	74.97	62.83	53.75
Discomfort hrs (all clothing) (hrs)	281.23	297.69	336.24	323.94	334.51	325.67	334.51	335.37	324.80	334.51	308.39	214.40
Fanger PMV ()	1.38	1.54	1.93	1.95	1.74	1.73	1.41	1.13	1.20	1.79	1.64	1.12
Pierce PMV ET ()	1.75	1.85	2.39	2.58	2.45	2.58	2.18	2.03	2.06	2.48	1.98	1.27
Pierce PMV SET ()	2.36	2.45	2.95	2.36	2.19	2.33	1.92	1.76	1.80	3.03	2.57	1.91
Kansas Uni TSV ()	1.42	1.46	1.75	1.58	1.46	1.45	1.28	1.13	1.17	1.60	1.55	1.27

20 degree

Month	2002	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air Temperature (°C)	28.50	29.10	30.32	31.25	30.71	30.57	29.94	29.23	29.38	29.60	29.43	27.94
Radiant Temperature (°C)	29.25	29.88	31.02	31.86	31.26	31.11	30.45	29.68	29.86	30.12	30.15	28.69
Operative Temperature (°C)	28.88	29.49	30.67	31.55	30.99	30.84	30.20	29.46	29.62	29.86	29.79	28.32
Outside Dry-Bulb Temperature (°C)	26.86	28.01	29.32	30.61	29.95	29.70	29.02	28.33	28.24	28.00	27.73	26.39
Relative Humidity (%)	63.07	63.42	66.33	66.33	68.62	73.15	69.15	72.11	72.26	74.83	62.71	53.75
Discomfort hrs (all clothing) (hrs)	281.07	297.86	336.24	323.94	334.51	325.67	334.51	335.37	324.80	334.51	308.57	215.01
Fanger PMV ()	1.38	1.55	1.95	1.97	1.75	1.75	1.43	1.15	1.22	1.80	1.65	1.11
Pierce PMV ET ()	1.75	1.85	2.40	2.59	2.46	2.59	2.19	2.04	2.08	2.49	1.98	1.27
Pierce PMV SET ()	2.36	2.45	2.96	2.37	2.20	2.34	1.92	1.77	1.81	3.03	2.57	1.91
Kansas Uni TSV ()	1.42	1.46	1.76	1.59	1.47	1.46	1.29	1.14	1.18	1.60	1.56	1.27

160 degree

Month	2002	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air Temperature (°C)	28.47	29.11	30.32	31.28	30.72	30.55	29.93	29.19	29.35	29.57	29.36	27.92
Radiant Temperature (°C)	29.24	29.89	31.00	31.87	31.27	31.09	30.44	29.65	29.82	30.09	30.10	28.68
Operative Temperature (°C)	28.85	29.50	30.66	31.58	30.99	30.82	30.18	29.42	29.58	29.83	29.73	28.30
Outside Dry-Bulb Temperature (°C)	26.86	28.01	29.32	30.61	29.95	29.70	29.02	28.33	28.24	28.00	27.73	26.39
Relative Humidity (%)	63.13	63.42	66.33	66.16	68.57	73.15	69.18	72.21	72.36	74.91	62.90	53.77
Discomfort hrs (all clothing) (hrs)	281.23	297.67	336.24	323.94	334.51	325.67	334.51	335.37	324.80	334.51	308.38	214.22
Fanger PMV ()	1.37	1.55	1.95	1.98	1.75	1.74	1.42	1.14	1.21	1.79	1.63	1.11
Pierce PMV ET ()	1.74	1.85	2.40	2.59	2.46	2.58	2.18	2.03	2.07	2.48	1.97	1.26
Pierce PMV SET ()	2.35	2.45	2.96	2.37	2.20	2.34	1.92	1.76	1.80	3.03	2.56	1.91
Kansas Uni TSV ()	1.42	1.46	1.76	1.60	1.47	1.45	1.28	1.14	1.17	1.60	1.55	1.26

Comfort Study at 90 meter
1 Jan. - 31 Dec. Monthly

0 degree

Air Temperature (°C)	28.73	29.16	30.56	31.48	31.00	30.72	30.22	29.49	29.74	29.93	29.55	28.12
Radiant Temperature (°C)	29.71	30.21	31.55	32.44	31.92	31.66	31.08	30.27	30.54	30.72	30.52	29.11
Operative Temperature (°C)	29.22	29.68	31.06	31.96	31.46	31.19	30.65	29.88	30.14	30.33	30.04	28.62
Outside Dry-Bulb Temperature (°C)	26.86	28.01	29.32	30.61	29.95	29.70	29.02	28.33	28.24	28.00	27.73	26.39
Relative Humidity (%)	62.55	63.44	65.81	65.71	67.77	72.80	68.34	71.31	71.06	73.62	62.44	53.37
Discomfort hrs (all clothing) (hrs)	281.58	297.72	336.24	323.94	334.51	325.67	334.51	335.37	324.80	334.51	308.21	214.46
Fanger PMV ()	1.48	1.62	2.07	2.16	1.96	1.91	1.63	1.34	1.45	1.94	1.73	1.20
Pierce PMV ET ()	1.83	1.88	2.48	2.67	2.56	2.67	2.29	2.14	2.20	2.58	2.03	1.32
Pierce PMV SET ()	2.43	2.48	3.03	2.45	2.31	2.42	2.03	1.88	1.94	3.12	2.62	1.97
Kansas Uni TSV ()	1.48	1.48	1.82	1.66	1.56	1.51	1.37	1.23	1.28	1.68	1.60	1.32

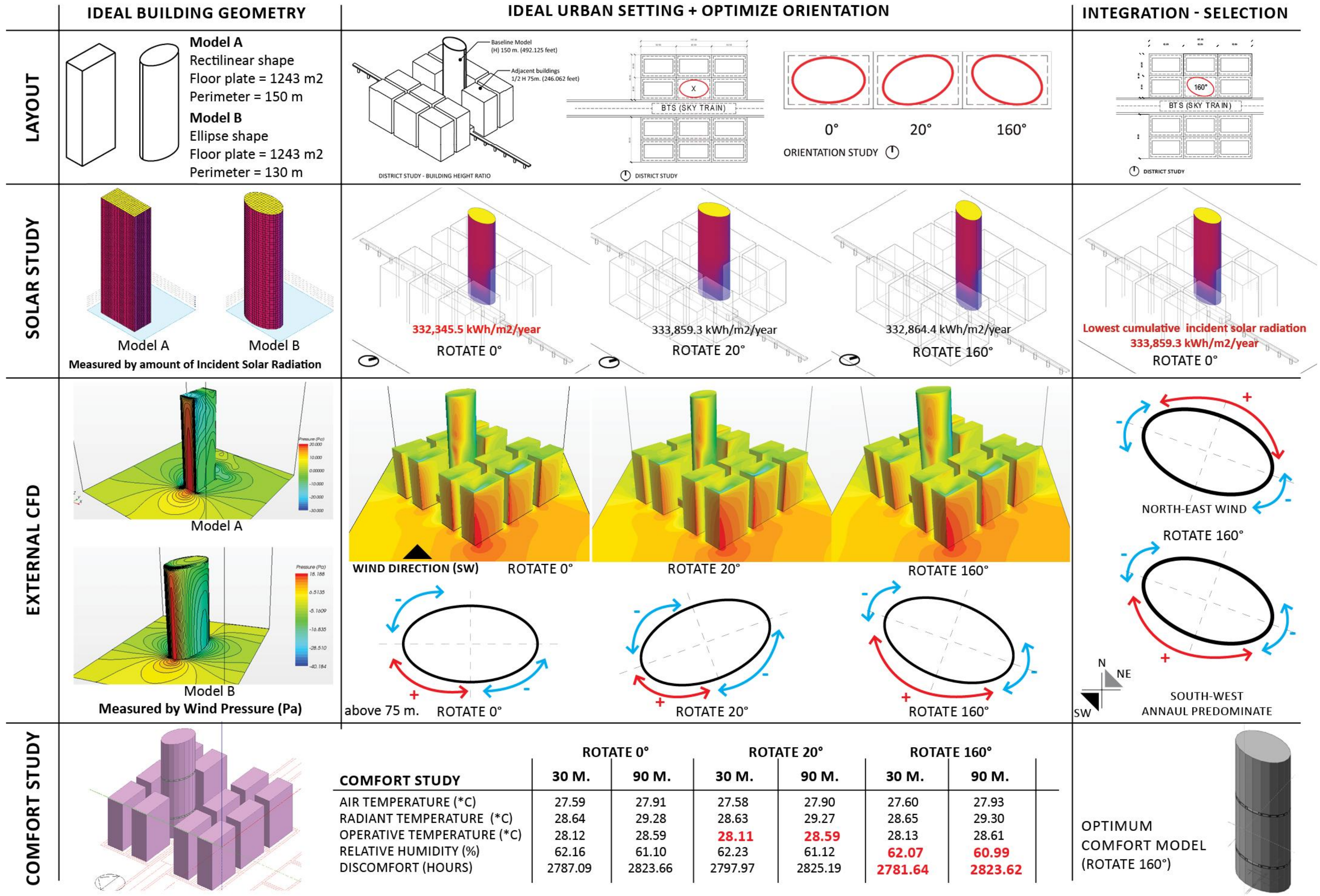
20 degree

Month	2002	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air Temperature (°C)	28.74	29.20	30.63	31.55	31.06	30.78	30.26	29.55	29.79	29.96	29.60	28.14
Radiant Temperature (°C)	29.71	30.24	31.64	32.53	31.99	31.72	31.13	30.34	30.61	30.75	30.55	29.11
Operative Temperature (°C)	29.22	29.72	31.14	32.04	31.53	31.25	30.69	29.95	30.20	30.36	30.08	28.63
Outside Dry-Bulb Temperature (°C)	26.86	28.01	29.32	30.61	29.95	29.70	29.02	28.33	28.24	28.00	27.73	26.39
Relative Humidity (%)	62.52	63.23	65.58	65.51	67.58	72.61	68.19	71.06	70.86	73.49	62.29	53.33
Discomfort hrs (all clothing) (hrs)	281.54	297.66	336.24	323.94	334.51	325.67	334.51	335.37	324.80	334.51	308.38	215.17
Fanger PMV ()	1.49	1.63	2.09	2.19	1.99	1.94	1.64	1.37	1.47	1.95	1.74	1.21
Pierce PMV ET ()	1.83	1.89	2.49	2.68	2.57	2.68	2.30	2.16	2.21	2.58	2.04	1.33
Pierce PMV SET ()	2.43	2.49	3.04	2.47	2.33	2.44	2.04	1.90	1.96	3.12	2.62	1.97
Kansas Uni TSV ()	1.49	1.49	1.83	1.68	1.57	1.52	1.38	1.24	1.29	1.69	1.61	1.32

160 degree

Month	2002	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air Temperature (°C)	28.72	29.22	30.64	31.57	31.07	30.76	30.25	29.50	29.76	29.94	29.52	28.11
Radiant Temperature (°C)	29.69	30.27	31.64	32.54	32.00	31.71	31.14	30.30	30.57	30.73	30.49	29.08
Operative Temperature (°C)	29.20	29.74	31.14	32.06	31.53	31.24	30.69	29.90	30.17	30.34	30.01	28.59
Outside Dry-Bulb Temperature (°C)	26.86	28.01	29.32	30.61	29.95	29.70	29.02	28.33	28.24	28.00	27.73	26.39
Relative Humidity (%)	62.61	63.22	65.55	65.38	67.53	72.62	68.20	71.22	70.96	73.57	62.54	53.41
Discomfort hrs (all clothing) (hrs)	281.55	297.44	336.24	323.94	334.51	325.67	334.51	335.37	324.80	334.51	308.16	214.47
Fanger PMV ()	1.48	1.63	2.10	2.19	1.99	1.93	1.65	1.35	1.46	1.94	1.72	1.20
Pierce PMV ET ()	1.82	1.89	2.49	2.69	2.57	2.68	2.30	2.15	2.21	2.58	2.02	1.32
Pierce PMV SET ()	2.42	2.49	3.04	2.47	2.33	2.43	2.05	1.89	1.95	3.12	2.61	1.96
Kansas Uni TSV ()	1.48	1.49	1.83	1.68	1.57	1.52	1.38	1.23	1.29	1.69	1.59	1.31

Table 7.1: Thermal comfort calculation results in the building orientations



COMFORT STUDY	ROTATE 0° 30 M.	ROTATE 0° 90 M.	ROTATE 20° 30 M.	ROTATE 20° 90 M.	ROTATE 160° 30 M.	ROTATE 160° 90 M.
AIR TEMPERATURE (*C)	27.59	27.91	27.58	27.90	27.60	27.93
RADIANT TEMPERATURE (*C)	28.64	29.28	28.63	29.27	28.65	29.30
OPERATIVE TEMPERATURE (*C)	28.12	28.59	**28.11**	**28.59**	28.13	28.61
RELATIVE HUMIDITY (%)	62.16	61.10	62.23	61.12	**62.07**	**60.99**
DISCOMFORT (HOURS)	2787.09	2823.66	2797.97	2825.19	**2781.64**	**2823.62**

7.16 The matrix of initial research study

Although the thermal comfort study did not yield enough differences in values for a conclusion, the thesis must move forward with the prototypical model. The matrix of initial research study presented in figure 7.15 summarizes the studies, from the ideal building geometry to the ideal urban configurations, yielding some guidelines that may inform design and even orientation. The comparison study on solar insolation shows that the relative numbers of the ellipse building in 20 degree orientation received the lowest solar energy on building surface. On the other hand, the building oriented in 160 degrees received the highest solar energy on the building surface; thus, creating the potential of a renewable energy supply from photovoltaic panels.

Natural ventilation uses the freely available resources of the wind and thermal energy that is a result of solar and incidental heating of the building to minimize energy demands. Although these resources are free, they are difficult to control. The challenge is to provide the necessary control mechanisms to develop the required indoor air quality. To achieve this, it is necessary to understand the physics of ventilation and how it relates to building orientation. Broadly speaking, pressures are higher on the windward side of the building and lower on the leeward side and on the roof and so will tend to drive a flow within the building from the windward vents to the leeward vents. Ventilation is essentially the flow of air between the inside and outside of a building. This flow occurs through vents, traditionally windows, but increasingly through purposely designed, controlled openings. The building orientation study found that a 160 degree orientation is optimal for ventilation because it provides a larger area of high pressure compared to the other configurations.

7.3 Schematic Transformation

Building geometry and orientation, and the surrounding built environment, is essential to any simulation of building performance. This paper presents an ellipse building geometry at 160 degrees orientation as the ideal for our conceptual urban district. For the schematic model development, I am proposing a conventional stacked building for a mixed-use program with the public spaces at ground level and the private residences above ground. The orientation provides the building with the maximum potential for natural ventilation by capitalizing on the external winds. The interplay of positive and negative wind pressure distributions enhances the mobility of air to move around the building, as well as through the internal space. To lessen the impact of thermal storage that is gained from the heat islanding effect, I am proposing a parking podium design. I addition, I am carving insets into the building geometry to capitalize on the airflow from the simulated urban context (figure 7.17). Open spaces and green spaces will also be a feature of the schematic model development as addressed in Chapter 7.

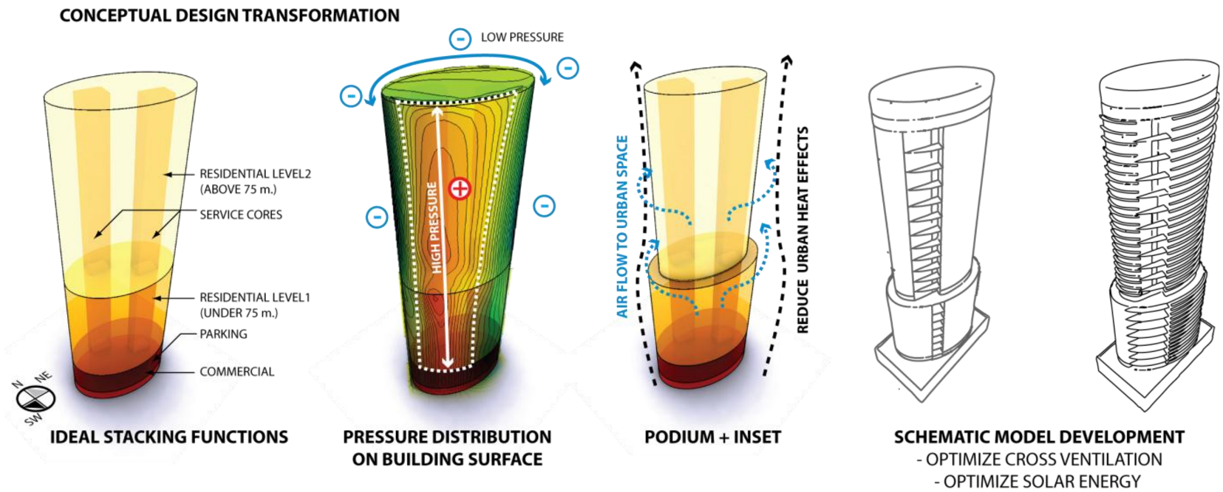


Figure 7.17: Conceptual building design transformation

The major building program (in figure 7.18) is residential function that is located on top of the parking podium. At the 75 meter (246 feet) mark in height, the resident tower is reduced in mass, thereby dividing the building into a lower and upper residential. While commercial retail are located at the ground level, open and green spaces are used in multiple locations, including transition floors between resident towers 1 and 2 and above the parking podium; and in the social spaces of every floor exposed to the high pressure area. Vertical green walls are placed in open spaces where soil is supplied.

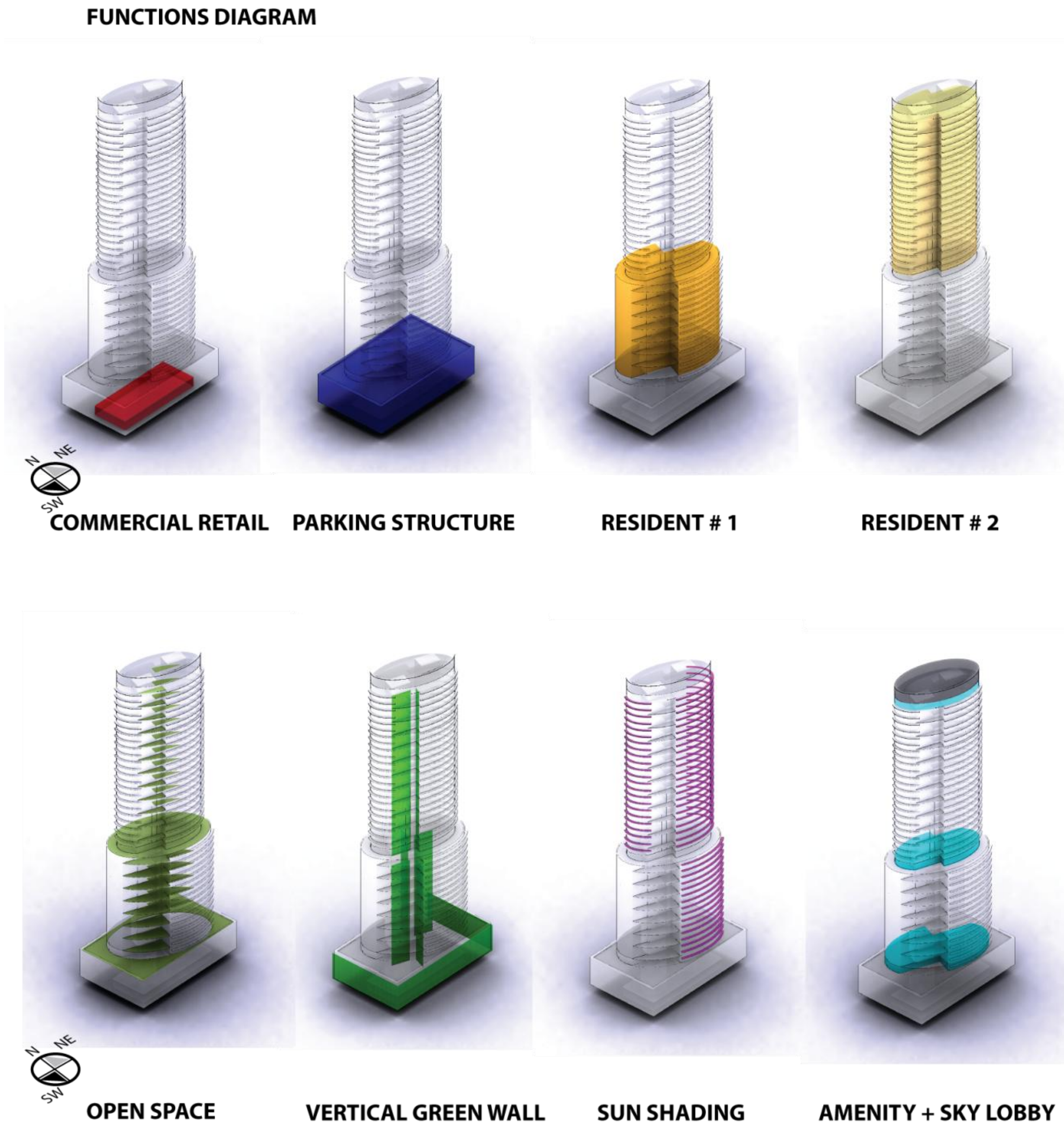


Figure 7.18: Functions diagram

Programs	Commercial retail	Parking	Residential 1	Residential 2	Openspace	Amenity - Sky lobby	Total area
GFA (m2)	2,202.92	8,811.68	13,569.75	10,829.61	6,444.08	2,231.70	39,389.19

Table 7.1: Programs and area summary

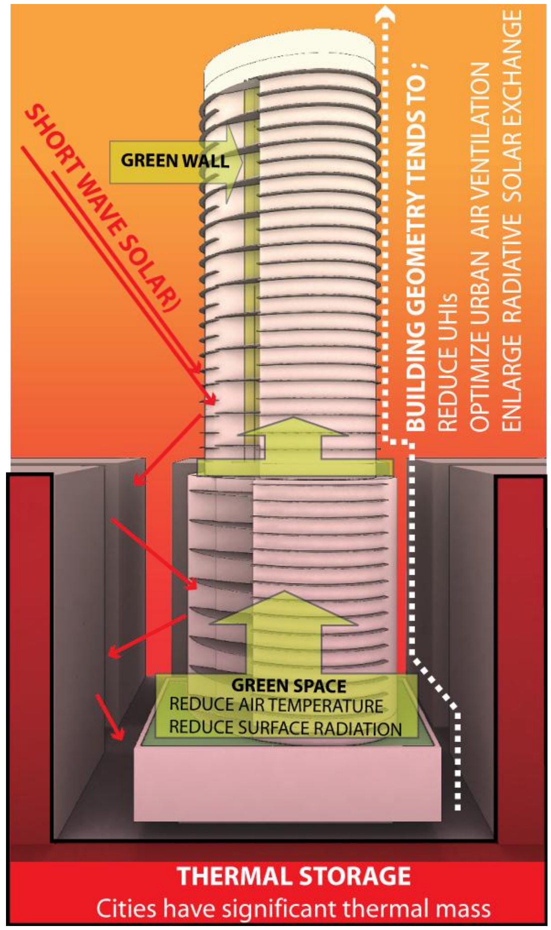


Figure 7.19: Schematic design approach on urban heat island

The urban heat islanding effect creates a significant rise in temperature, especially with a high density of surrounding buildings. Impervious surfaces, such as sidewalks and streets, store heat at the ground level, especially between tight building spaces. In addition, these surfaces also radiate heat to the surrounding environment. This means that in an area dense with buildings, the shortwave cannot reflect heat back to the atmosphere. Instead the heat is reflected to other impervious surfaces, which is stored in the lower level. Thus, the obvious solution to reduce urban heat islanding is to provide more pervious surfaces, such open and green spaces. The schematic design (figure 7.18) has developed from a simple, ellipse geometry with a 120 degree orientation to a stacked building volume in a conventional podium style with open spaces, vertical green walls and shading features. The design is intended reflect heat radiation back to atmosphere. With over 6,000 m2 of open and green spaces located on ground level and above the parking podium, the design is able to cool down ground temperature, as well as filter noise pollution.

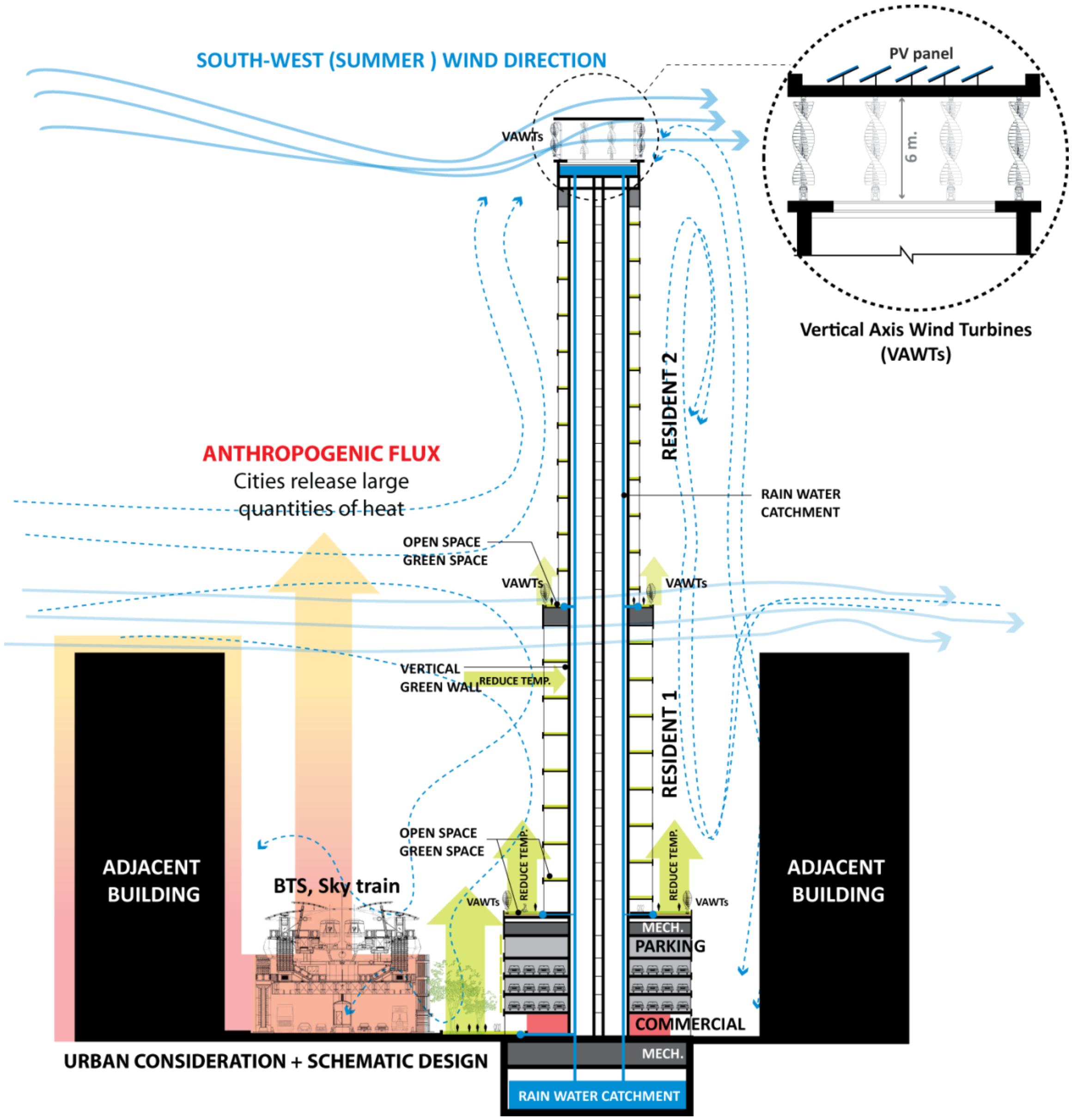


Figure 7.20: Interaction between building design and urban context

The schematic building design in figure 7.19 shows a conceptual diagram on how open and green spaces interact with building design to mitigate heat islanding effect and increase natural ventilation. The open and green spaces become an area for social interaction in each residential floor. At ground level, the natural landscape is designed to filter the noise pollution from the elevated train the ground and transportation. The parking podium and the carved insets into the building geometry are designed to capitalize on the airflow from the conceptual urban context. The rainy season in Thailand is characterized with heavy pour onto impervious surfaces resulting in water runoff and sometimes flood. The runoff becomes contaminated with dirty streets and sewer canal. Needless to say, Bangkok is in desperate need for design strategies to mitigate rain for more useful purposes. The schematic building design aims to capture rain from roof tops and permeable, open spaces; which should yield about 5% of total amount of water used by the tenants (4.5 gallons/person/day). Moreover, there are two feathers of renewable energy applied in the schematic design: photovoltaic panels attached to sun shading devices and overhangs (figure 8.12); and Wind turbines with photovoltaic capabilities (figure8.15) on roof gardens and roof tops, which are able to produce an efficient energy under low wind velocity.

7.4 Influences to architectural design

7.41 External wind study on building façade

Ventilation is essentially the flow of air between the inside and outside of a building. This flow occurs through vents, traditionally windows, but increasingly through purposely designed, controlled openings. The challenge is to provide the necessary control mechanisms to develop the required indoor air quality. To achieve this, it is necessary to understand the physics of ventilation. Thus, the location of external wind pressure plays a crucial role in cross ventilation. Cross ventilation takes air from high pressure areas or stagnation points and draws wind through the building and over to another side of building where the pressure is lower. Figure 7.21 is the computational fluid dynamics (CFD) simulation from Star CCM+ demonstrates the wind pressure (pa) conditions on building surfaces during summer and rainy seasons. The simulation was centered on wind-driven flows generated by wind tunnel conditions. Models of buildings are examined in an airstream and the pressure distributions around the building are measured for various orientations of the incident wind. Pressure distributions are determined and these are used to calculate the flow through vents at different locations on the facade. The insets of the schematic model yield high pressure winds, making them an obvious area to draw air from and vent to areas of lower pressure, such as another side of open space and on south-east and north-west view where the corridor ends are (figure 7.22 and 7.23).

Although the wind simulations were only generated during the summer and rainy seasons with predominant wind coming from the southwest, streamlines and pressures can be deducted for the winter season since the prevailing winds come from the opposite direction (northeast) and symmetrical patterns can be used as guidelines.

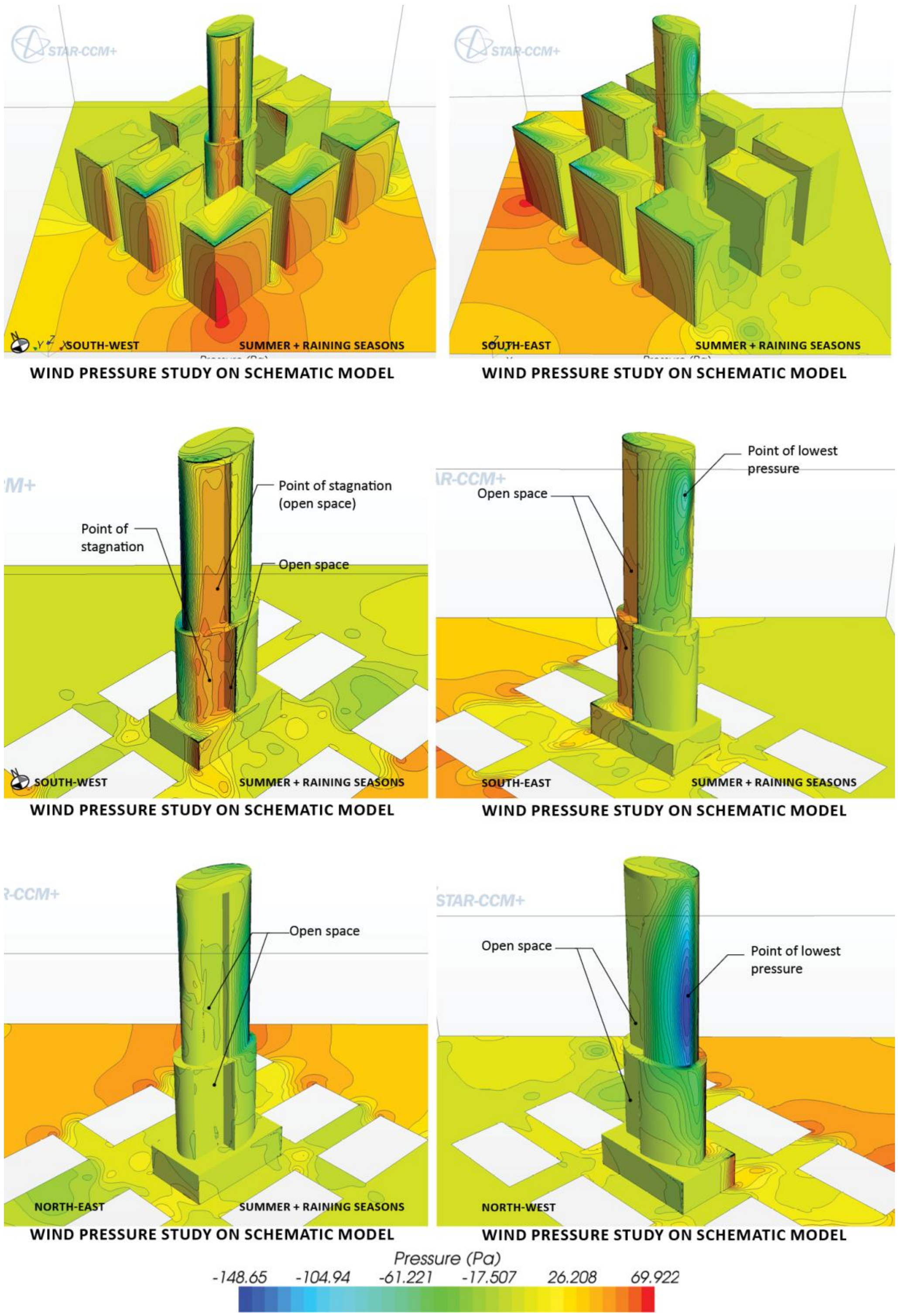


Figure 7.21: Wind pressure study on building façade
Resource: CD-Adapco , Star CCM+ CFD simulation

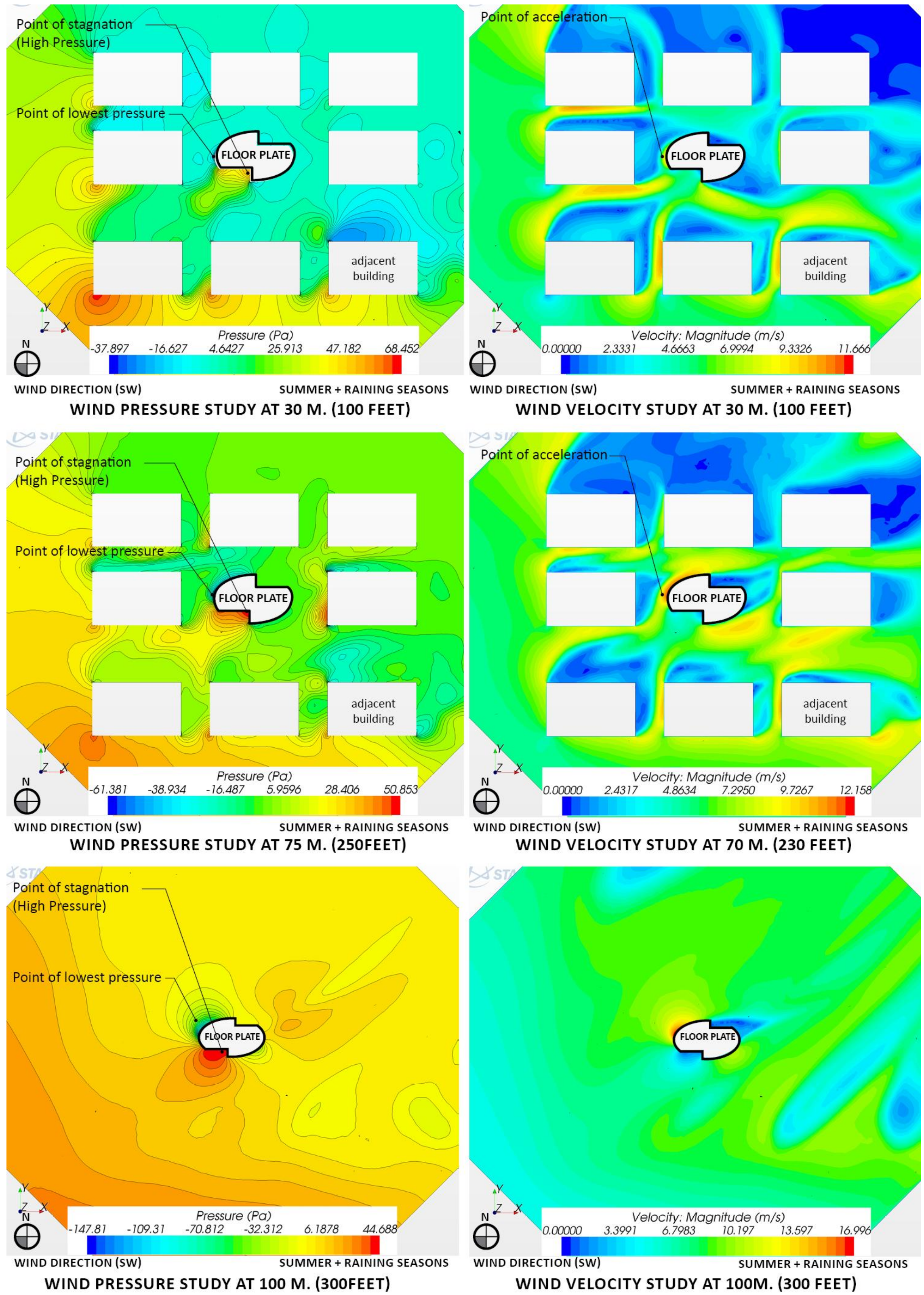


Figure 7.22: Wind velocity study on building façade
Resource: CD-Adapco , Star CCM+ CFD simulation

The propose of the schematic design is to provide an optimum positive wind pressure on the open space in each floors for cross ventilation from the positive pressure (windward side) to negative pressure (leeward side). The simulation model revealed large positive pressure at the windward inlet of the geometry, at the stagnation point around the open space above of the upper residential tower (figure 7.23). In addition, above the 75 meters, there are lower pressure areas around the adjacent buildings. Figure 7.23 shows a significant potential for cross natural ventilation since the pressure differential is about 50 – 60 pa[6]. However, the lower residential tower displays inefficient pressure differentials for natural ventilation, which may have an impact on thermal comfort issues in those residential floors.

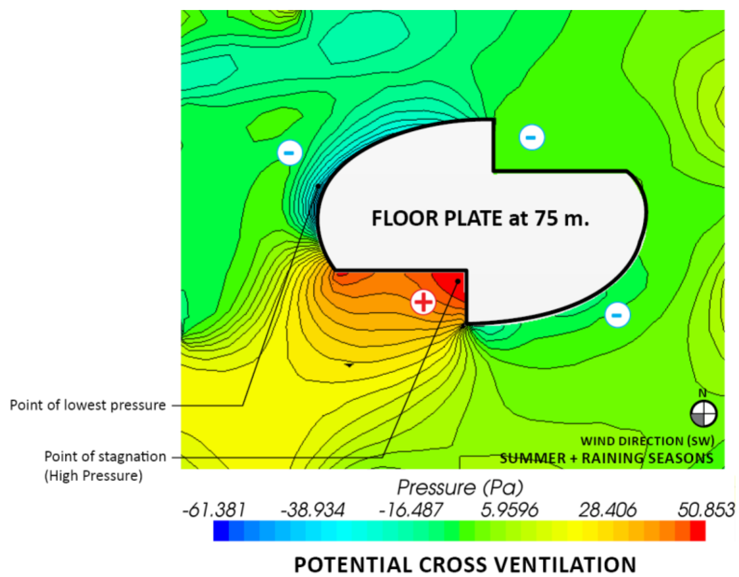


Figure 7.23: Potential cross ventilation
Resource: CD-Adapco , Star CCM+ CFD simulation

Figure 7.22 shows a wind study of pressure distribution and velocity at different floor levels; 30 meters, 70 meters, and 100 meters. This study helps to define both wind pressure and velocity condition from different floor levels. The 100 meter mark contains the highest pressure points on south-west façade, especially in open spaces. With a high volume of pressure and no obstructions along the building surface, there exist a huge opportunity for natural ventilation.

[6] Passive House Institute US, http://www.passivehouse.us/passiveHouse/PHIUSHome.html

7.4.2 Solar insolation on building façade

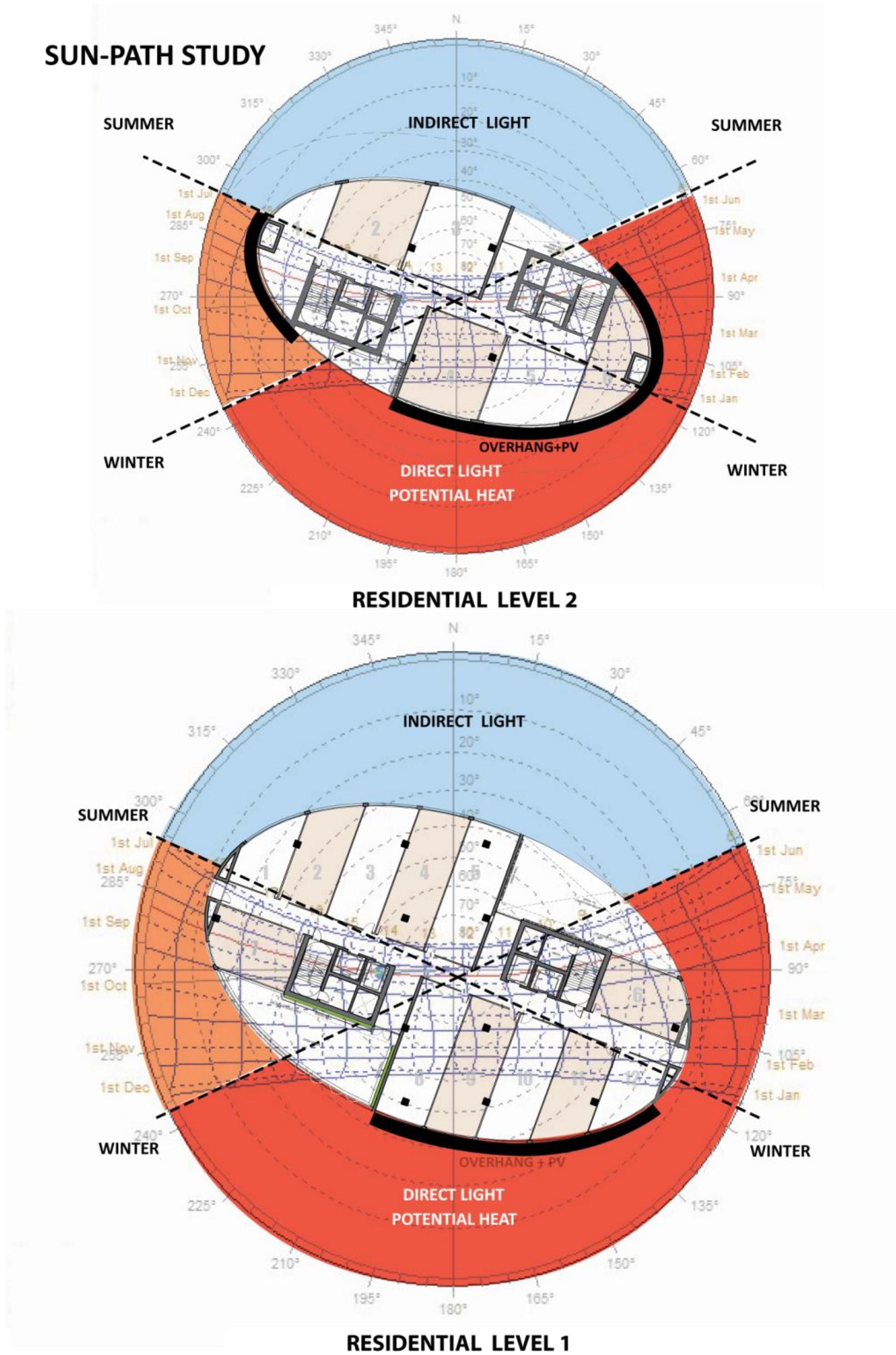


Figure 7.24: Sun-path study and building layout

Figure 7.24 addresses the relationship between the schematic floor layout design and sun-path diagram to help define the advantages of solar energy and disadvantages of solar again. The residential towers will have direct beam issue over the north façade during the summer months. The south façade have sun shading devices with PVs attached that so that it can double as sun protector and an energy generator. During low sun altitudes, the PV panel overhangs are not large enough to prevent direct solar gain. Therefore, light shelves are used to avoid direct solar beam and to provide indirect light into the interior spaces. The overhangs on the lower residential tower are only located in the south, because the other apartments are located beyond the heat zone. In addition, the lower towers are surrounded by adjacent buildings, which provide obstruction for direct heat gain. The upper residential tower is above 75 meter and has no obstruction for direct light. Therefore, the overhangs on the south have to continue up and overhang for the east and west has to be added to avoid the heat zone.

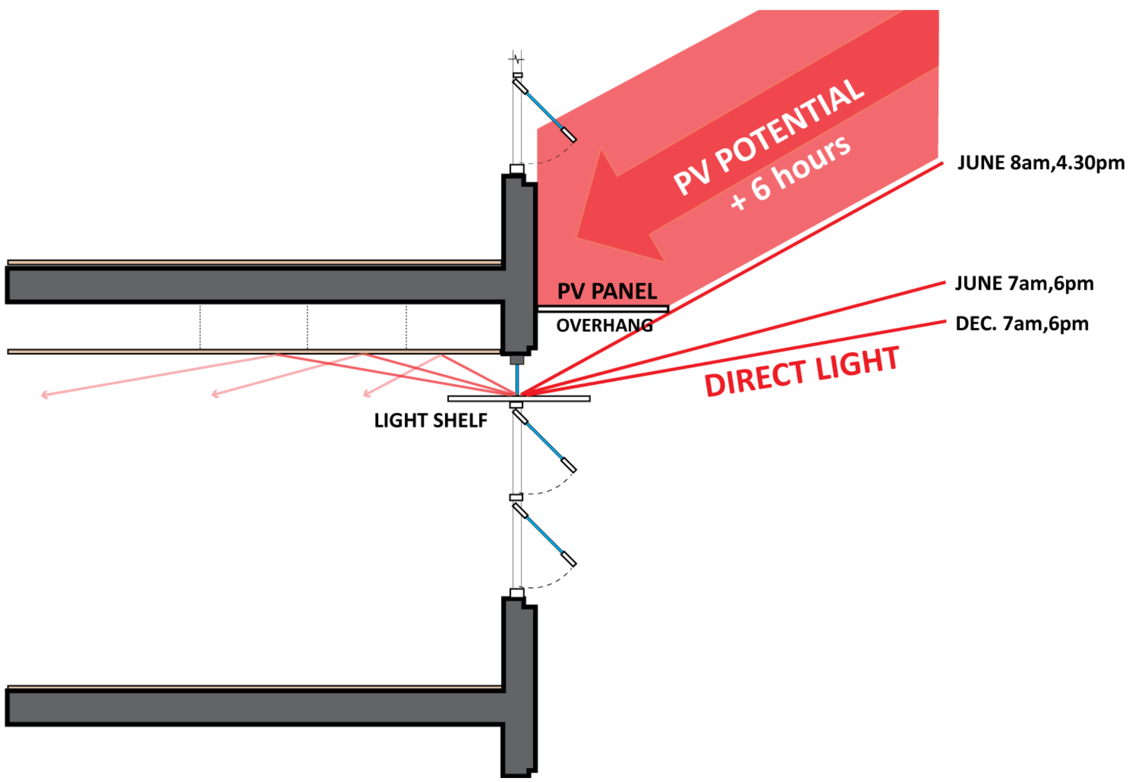


Figure 7.25: Overhang study and potential photovoltaic

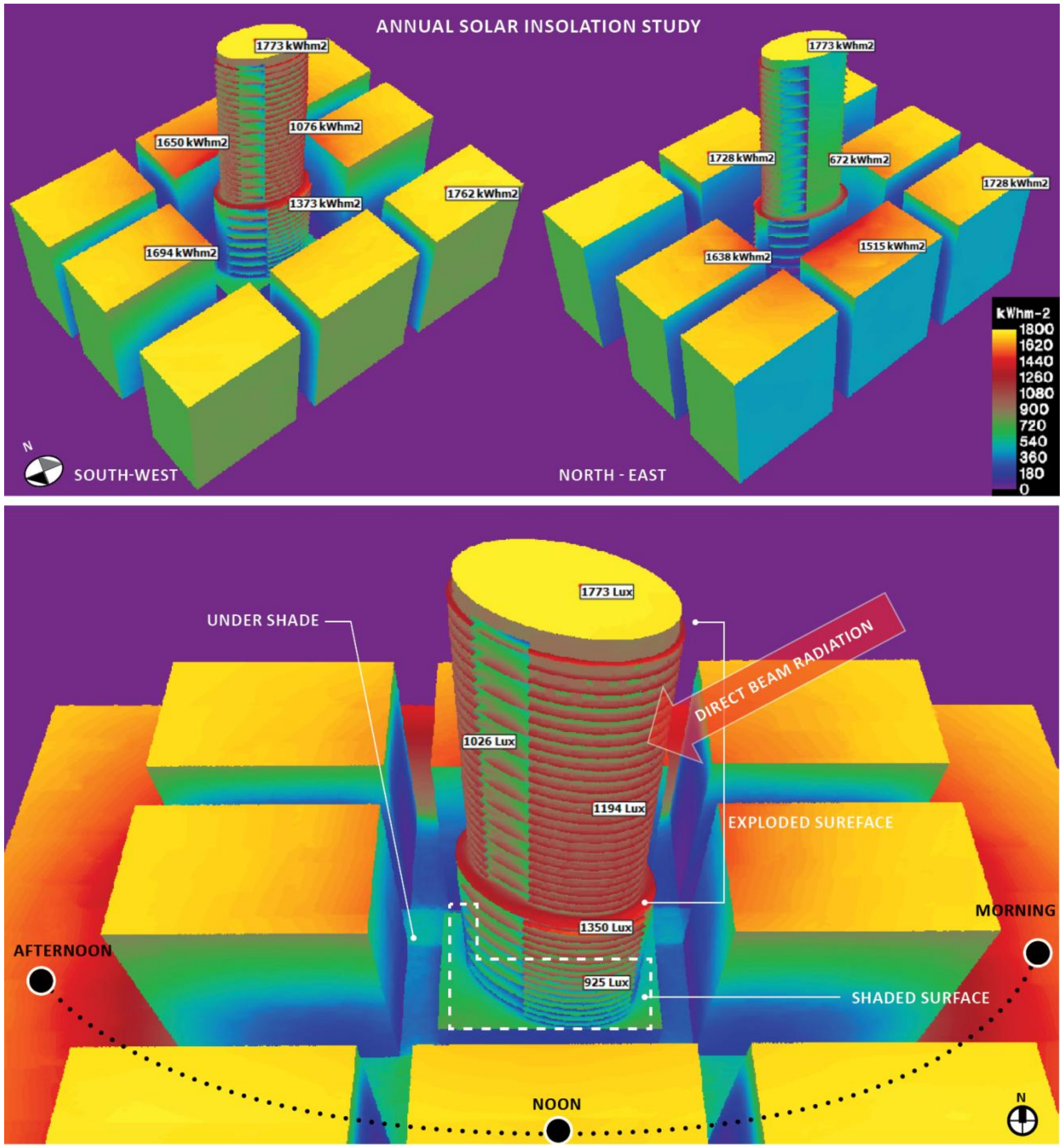


Figure 7.26: Annual solar Insolation study
Resource: DIVA, radiance map simulation

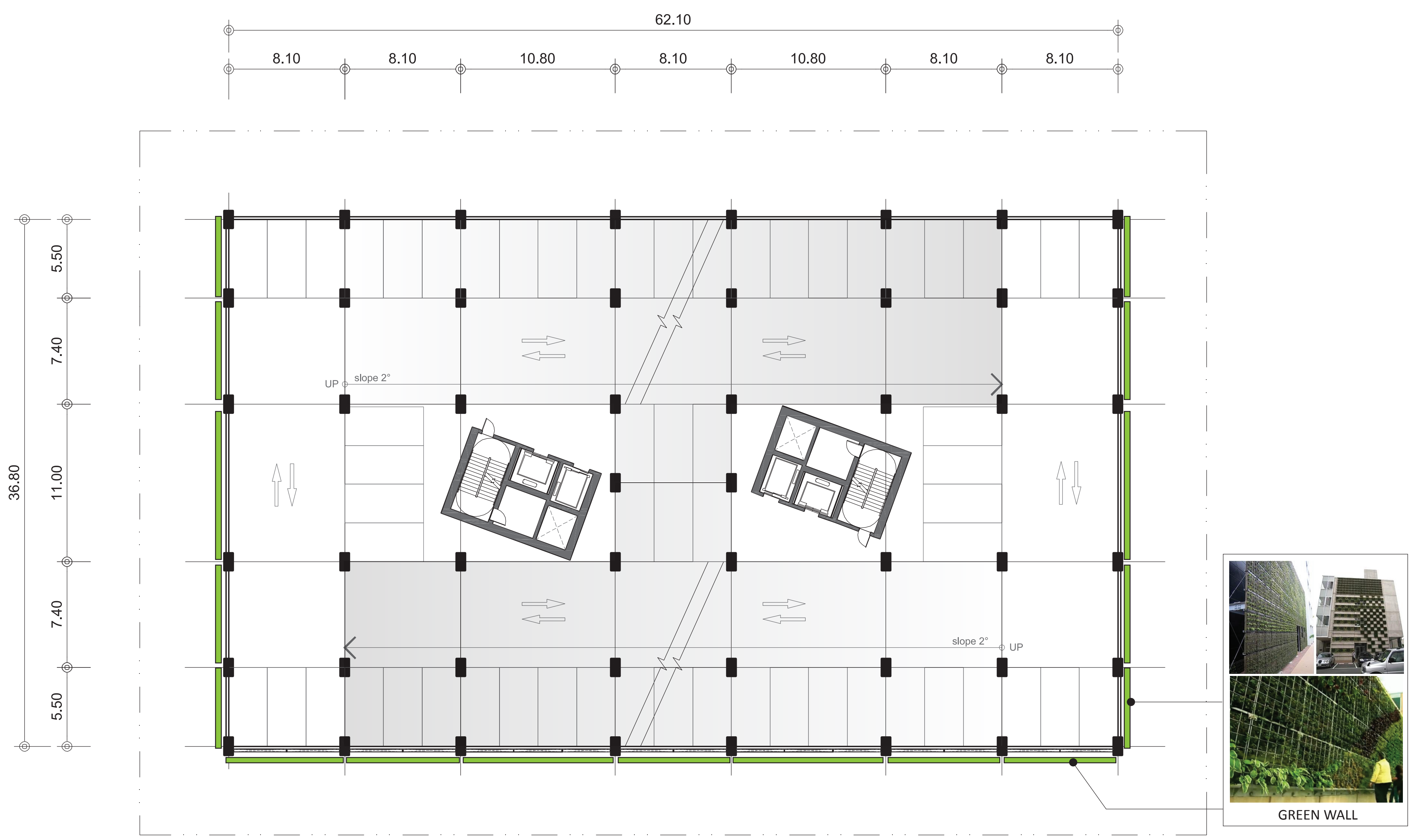
The radiance map simulation in figure 7.26 shows amount of solar energy on the building surfaces in the simulated urban context that creates both of positive and negative impact into the building. The simulation confirms that the lower residential tower is shaded by adjacent buildings and would not have sufficient lighting for PV panels. Therefore, the photovoltaic panels (PV) must be only be used on the upper towers to optimize solar energy (figure 8.6). Since Bangkok is above the equator, the south façade will yield the best results the PV systems.

7.4.3 Schematic floor layouts

From figure 7.27 to 7.30 are all schematic design layouts and there are some examples of renewable and sustainable technologies.

- Figure 7.27 is a ground floor layout and parking layout
- Figure 7.28 is all roof garden layouts
- Figure 7.29 is a residential level 1
- Figure 7.30 is a residential level 2

CUT



PARKING LEVEL 0 5 10 20 meter N

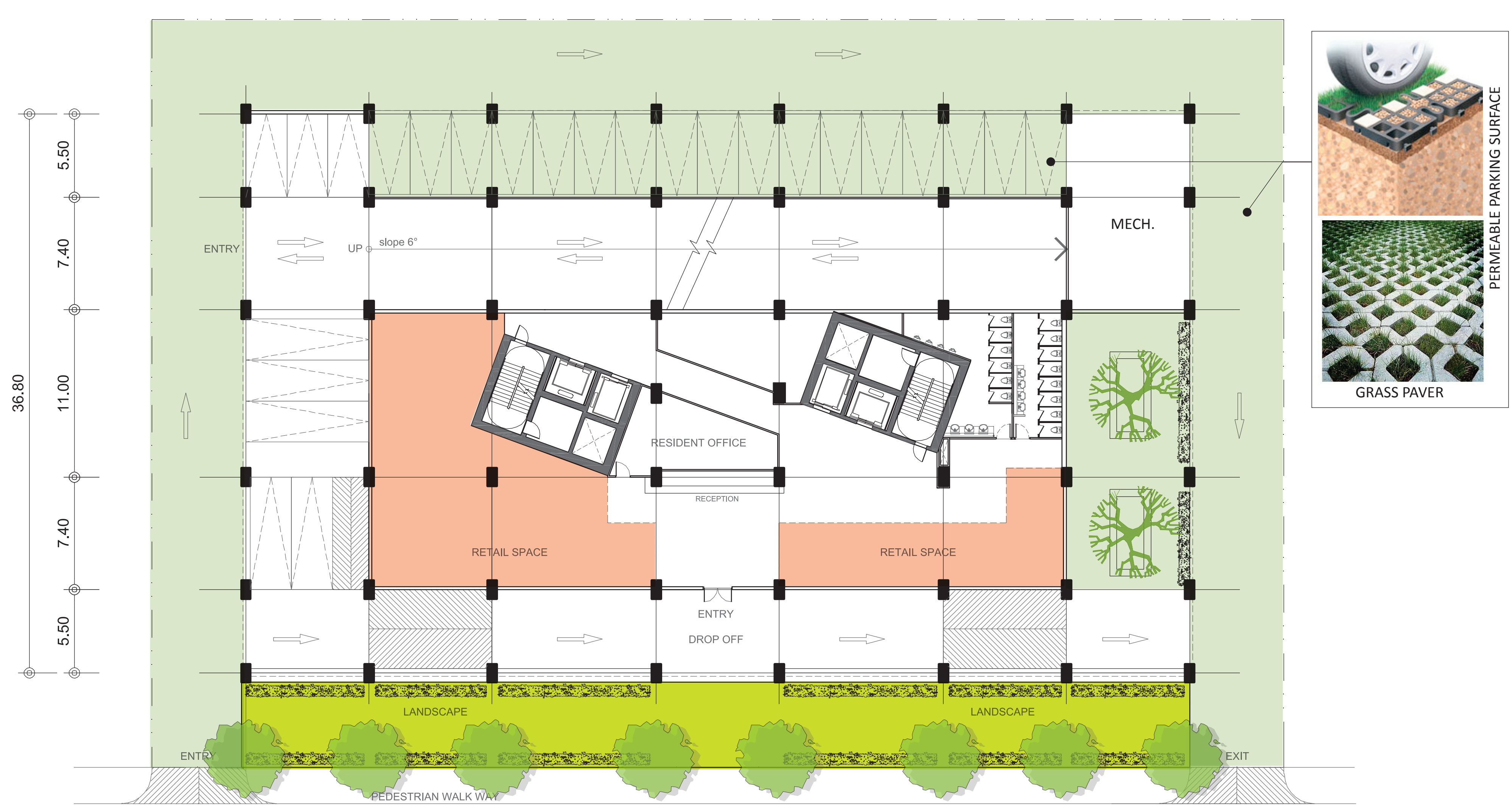
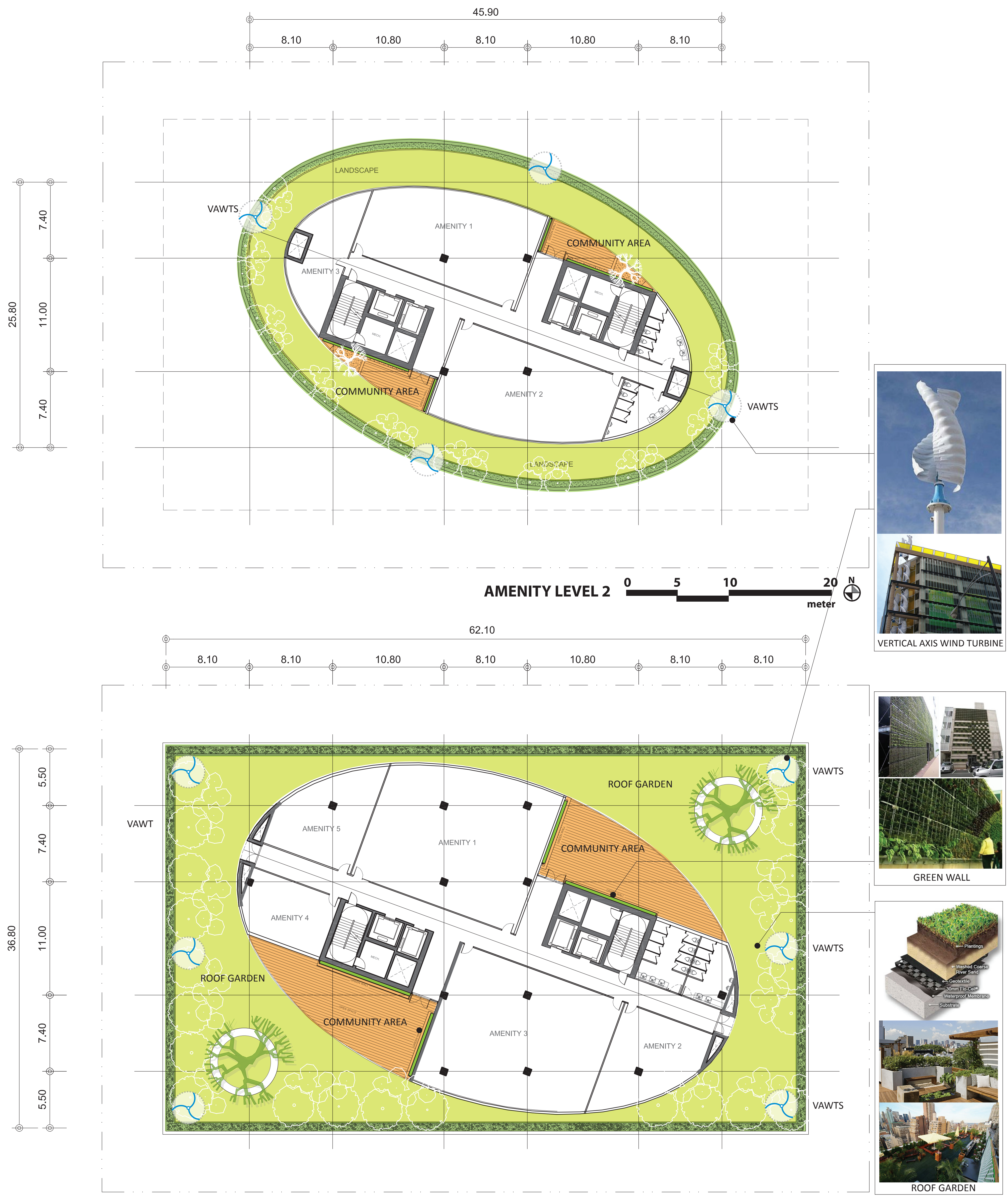


Figure 7.27, page 106

GROUND LEVEL 0 5 10 20 meter N

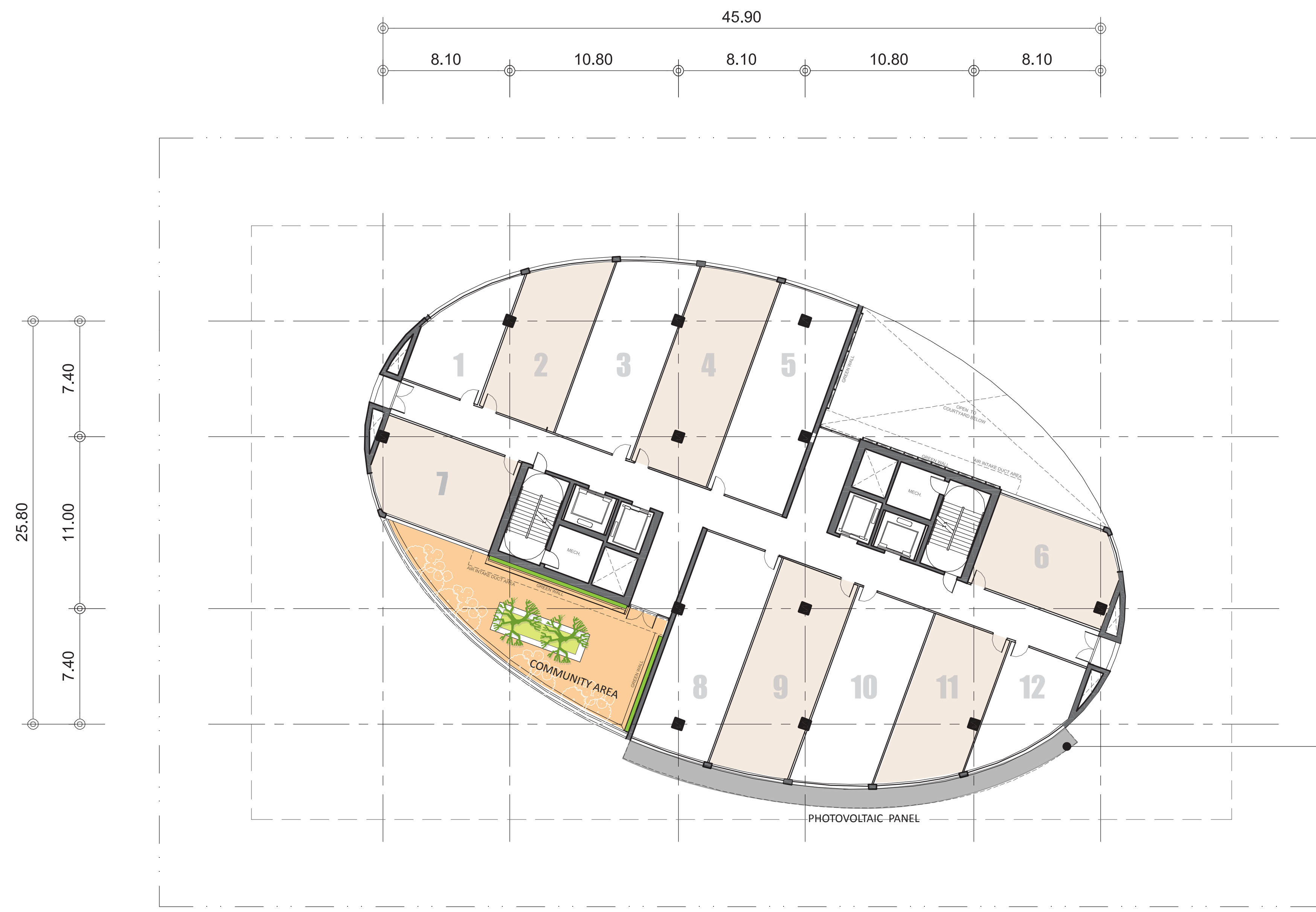
CUT



AMENITY LEVEL 1 0 5 10 20 meter N

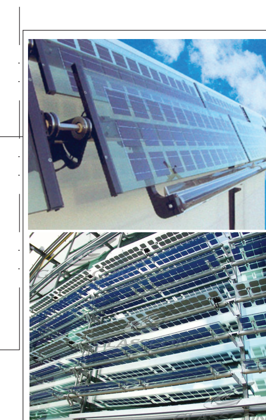
Figure 7.28, page 107

CUT

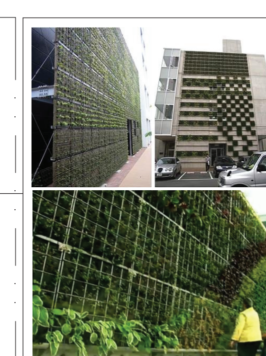


RESIDENTIAL LEVEL 1
ODD FLOOR NUMBER

0 5 10 20
meter



PHOTOVOLTAIC PANEL



GREEN WALL

ROOF GARDEN

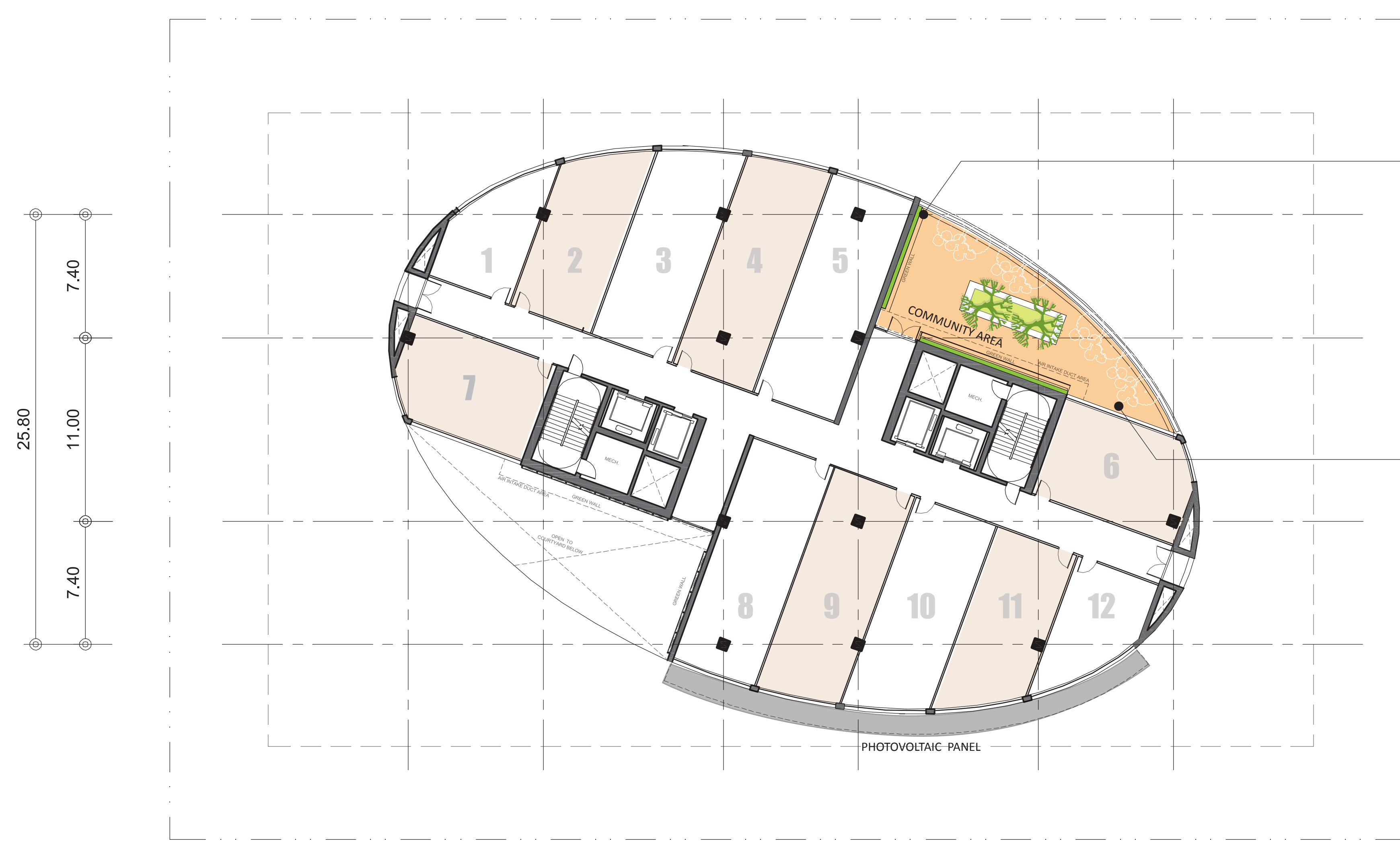
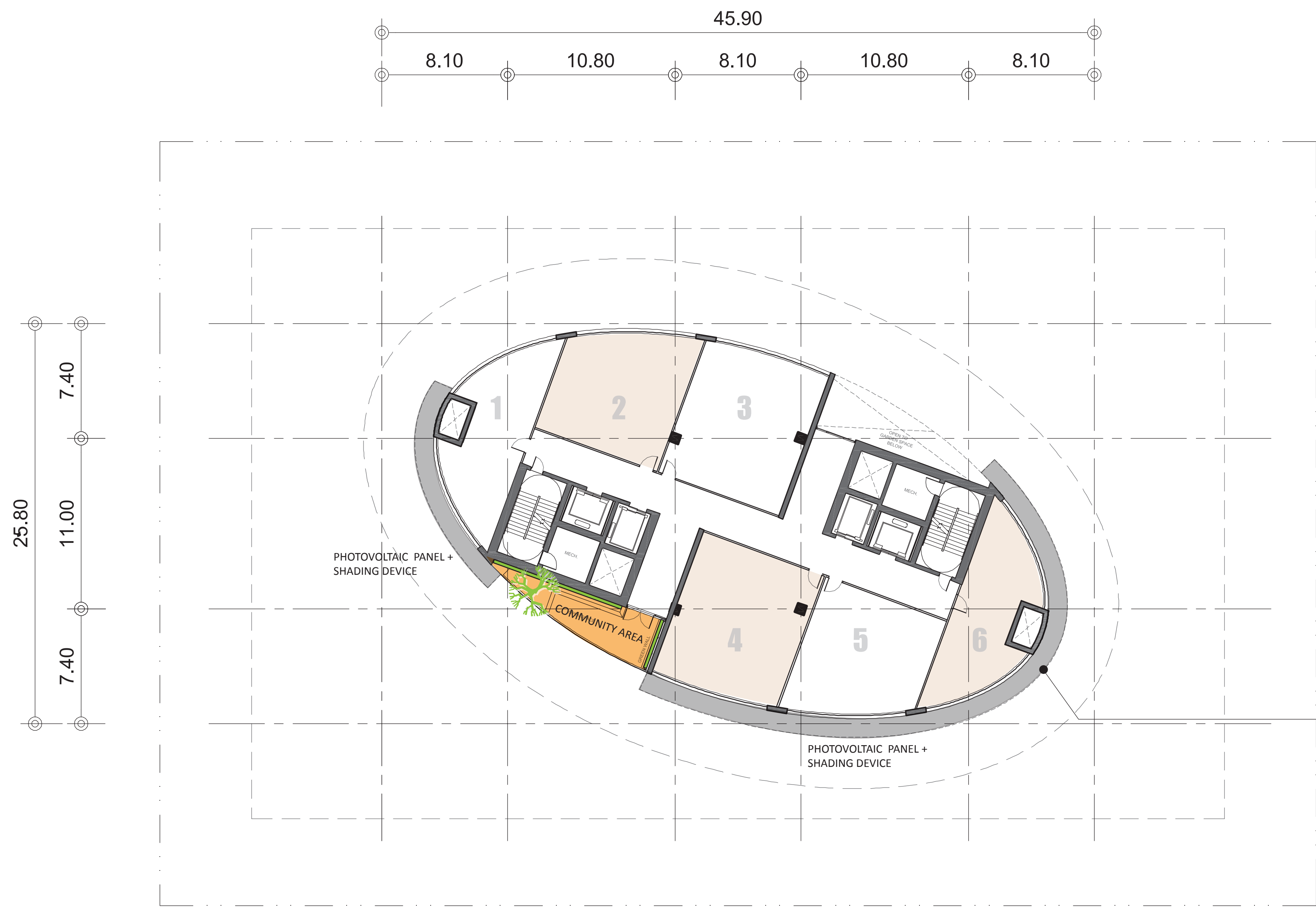


Figure 7.29, page 108

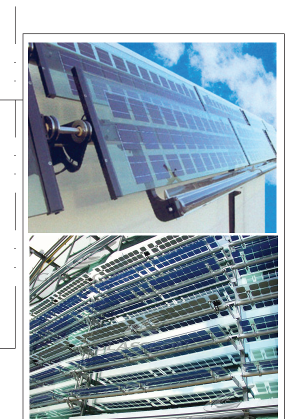
RESIDENTIAL LEVEL 1
EVEN FLOOR NUMBER

0 5 10 20
meter

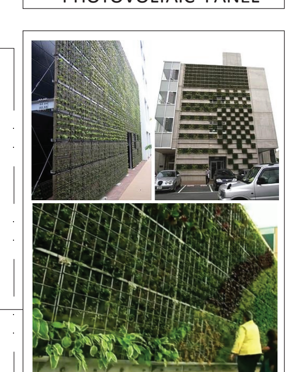
CUT



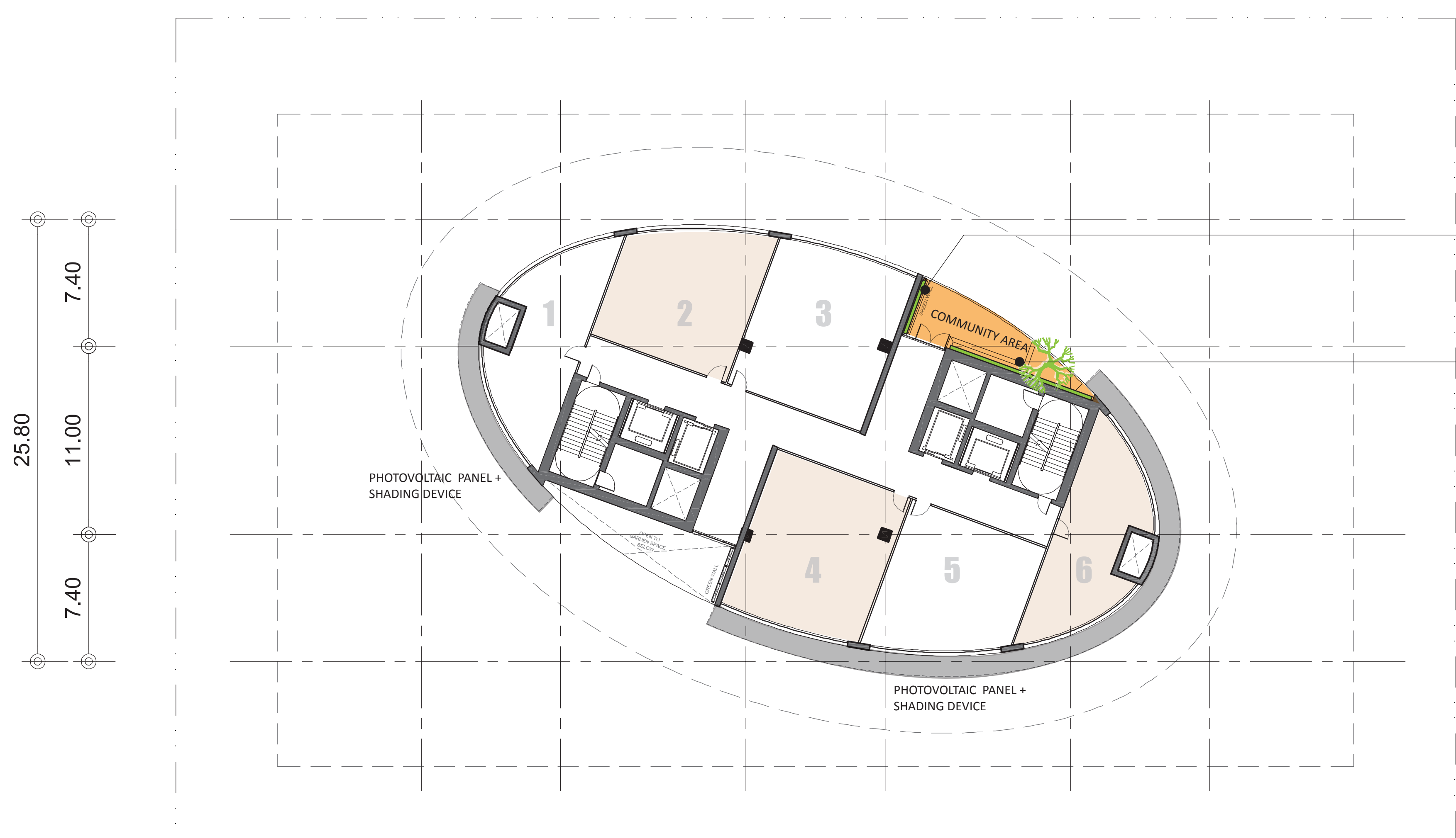
RESIDENTIAL LEVEL 2
ODD FLOOR NUMBER



PHOTOVOLTAIC PANEL



GREEN WALL



ROOF GARDEN

RESIDENTIAL LEVEL 2
EVEN FLOOR NUMBER

Figure 7.30, page 109

Chapter 8

Energy calculation and simulation

In pursuit of a net zero energy building design, this research advocates for the use of natural ventilation as the most effective passive design strategy. Natural ventilation uses the freely available resources of the wind and thermal energy that is a result of solar and incidental heating of the building. Although these resources are free, they are difficult to control. The challenge is to provide the necessary control mechanisms to develop the required indoor air quality. To achieve this, it is necessary to understand the physics of ventilation and the environmental constraints of an urban setting such as: density of buildings, air pollution, impervious surfaces, decreased wind flow, etc. This research statement has aggressively addressed strategies to reduce the massive energy use from the HVAC system. Proposing a 100 % natural ventilation strategy to replace HVAC systems in residential spaces is a risk and challenge. How can we determine whether a building can meet a thermal comfort level?

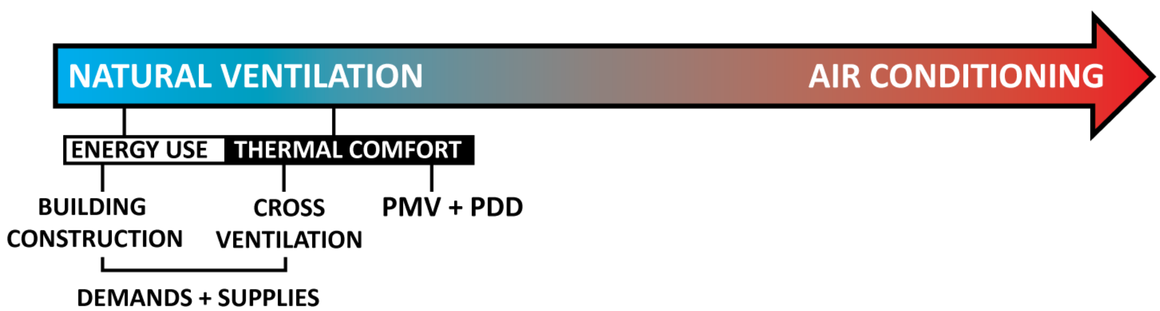


Figure 8.1: Research approach diagram

This chapter will present an analysis of indoor air quality with natural ventilation and mechanical ventilation. The comparative study will measure energy use and internal thermal comfort in respects to ambient temperature, mean radiant temperature, operative temperature, relative humidity, discomfort hours, PMV (predicted mean vote) and PPD (predicted percentage dissatisfied). The research outline aims to compare natural ventilation against mechanical ventilation to observe how much thermal comfort will change upon categories. The research methodology is using calculation and simulation to analyze indoor air quality of both conditions. The energy calculation will test the possibility whether a residential building can be net zero energy.

The simulation is centered on wind-driven flows. Models of buildings are examined in an airstream and the pressure distributions around the building are measured for various orientations of the incident wind. Pressure coefficients are determined and these are used to calculate the flow through vents at different locations on the façade.

8.1 Natural ventilation

Natural ventilation of buildings is the flow generated by wind pressure differences and by the temperature. The governing feature of this flow is the exchange between an interior space and the external ambient. The main problem concerns airflow patterns within the building. This may be a single space, but usually it is an interconnection of multiple spaces connected by openings (often doorways or hallways). This research analyzed the energy performance and internal thermal comfort condition in a specific floor level at 75 meters (about 250 feet above ground). The purpose is to show seasonal wind flow through the floor plan. The residential floor plan was designed to capitalize on positive wind pressure directions for cross ventilation.

8.1.1 Cross ventilation

Cross ventilation relies on wind to force cool exterior air into the building through an inlet and to force warm interior air out of the building through an outlet. Figure 18.1 is a diagram of general wind flow response to differing seasonal predominant wind directions. Wind travels from the outside to interior space from the higher pressure on windward façade to negative pressure on leeward side. The floor plan reveals a fascinating branch of fluid mechanics. The aim behind the floor plan is to exploit the rules and intuition on how air moves within a building. The zigzag layout of the hallway that opens to the wind capitalizes the pressure differential. The inset of the exterior volume contains the initial high pressure zone. As air travel through the building, it reaches the end of the hallway, resulting in another high pressure zone. From there, the low pressure zones at the other three openings pull the air through the hallways. This interplay of positive and negative pressure is the key to natural ventilation.

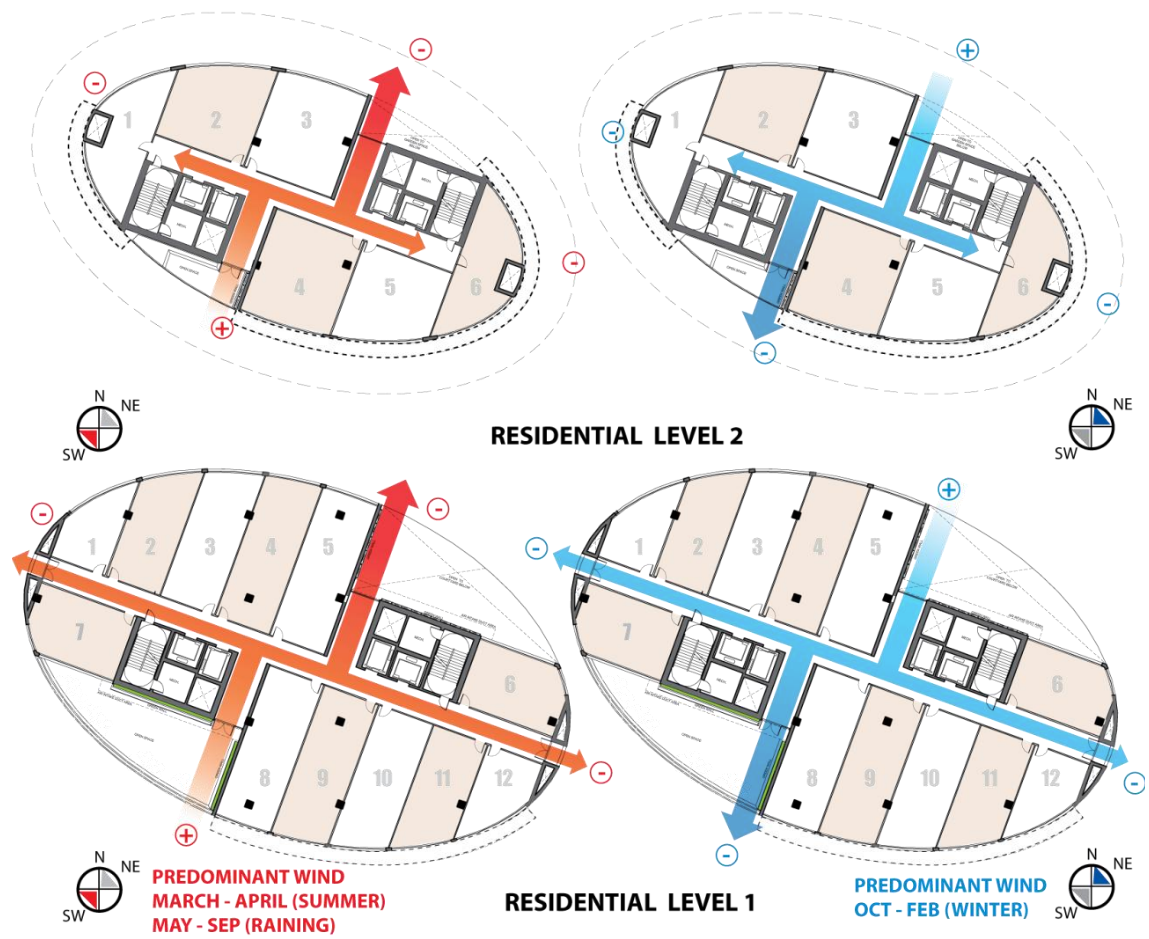


Figure 8.2: Cross ventilation diagram in both major seasons and directions

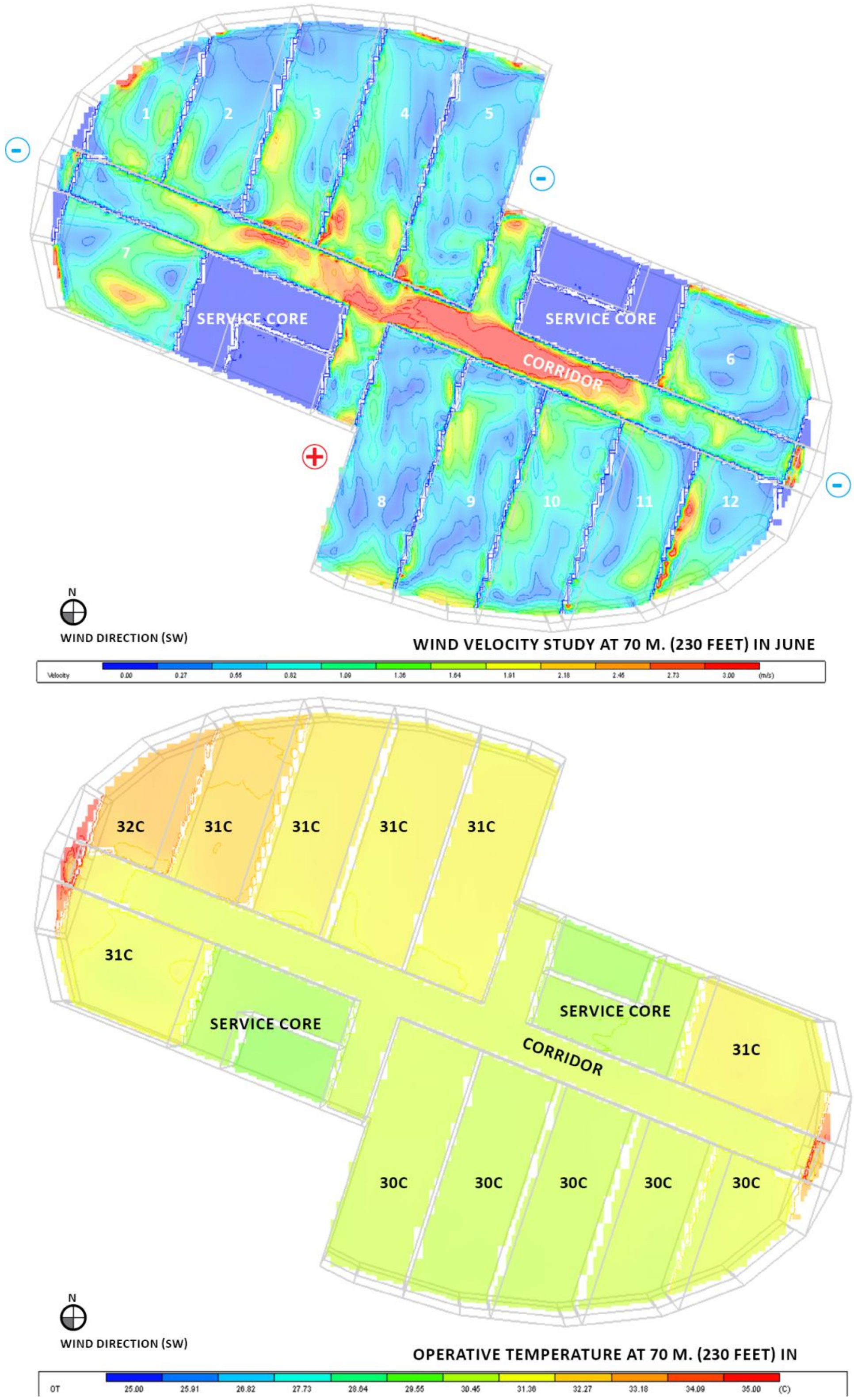


Figure 8.3: Wind velocity of cross ventilation (above) and Operative temperature (below) in June
Resource: DesignBuilder internal CFD simulation

According to DesignBuilder internal computation fluid dynamic (CFD) simulation in figure 8.3, the internal wind velocity is within a range 0 m/s – 3 m/s. The internal CFD simulation is a snapshot of time that represents the wind velocity in June. The interior space has a high wind energy movement. The flow pattern gently starts from the corridor opening on the southwest façade, travels through the remaining corridors and vents out on the northeast façade. The wind pattern also streamlines to the end of corridors on the east and west sides. The range of velocity is slightly above the human comfort level (figure 8.10). However, a comfort zone may be determined given the values of humidity, air speed, metabolic rate, and clothing insulation, a comfort zone may be determined.

The comfort zone can be defined in two terms: (1) the range of operative temperatures that provide acceptable thermal environmental conditions or (2) the combinations of air temperature and mean radiant temperature that people find comfortable. An operative temperature simulation in figure 8.3 below shows a range of operative temperature from 29C to 31C (84.2F – 87.8 F), which is typically higher than outdoor temperature.

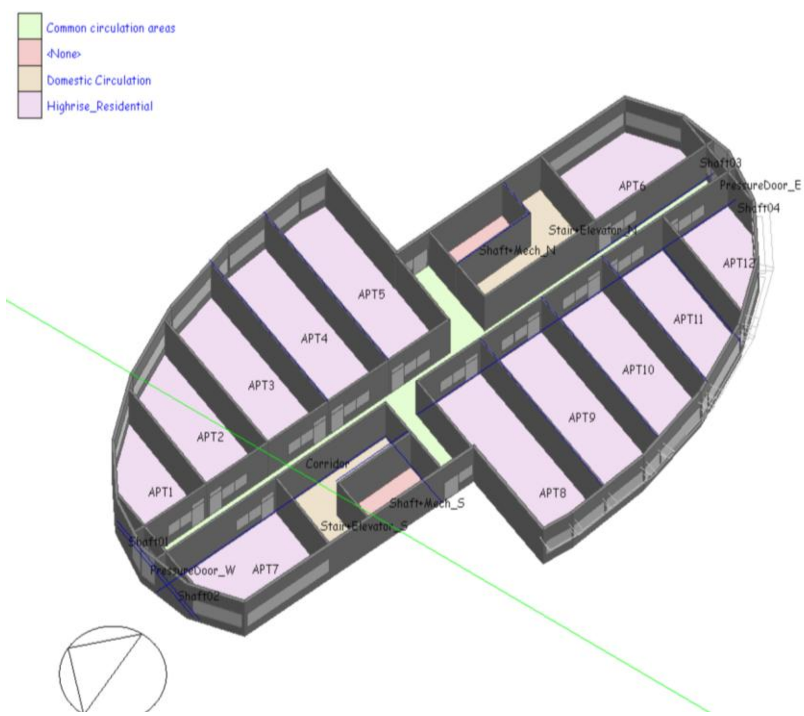


Figure 8.4: Internal floor residential layout at 75 meter
Resource: DesignBuilder model interface

8.1.2 Building construction

Although natural ventilation may often appear to be the dominant driving mechanism for human comfort, in many circumstances construction components play a controlling feature for the desired interior conditions. The consensus standards for thermal conductivities are developed and published by ASHRAE. These consensus standards define minimum values or acceptable performance by designating appropriate U-factor values for construction elements. This research explored and modified constructions, materials, and other configurations in order to improve the energy performance and thermal comfort (table 8.1). The study starts by using ASHRAE 90.1 SI 2010 climate zone 1 to apply construction properties, thermal conductivity, and fenestration as close as possible to ASHRAE which is a "Construction A". There are some adjustments afterward to improve a conductivity level as well lighting power density (LPD). Therefore, "Construction B-2" is a key significant to the final energy simulation and thermal analysis (see comparative internal thermal comfort in table 8.2).

	ASHRAE 90.1 SI 2010 (Zone 1)	**Construction A (Based on ASHRAE)**	**Construction B-1**	**Construction B-2**
Construction Elements	U-factor (W/m2-K)	U-factor (W/m2-K)	U-factor (W/m2-K)	**U-factor (W/m2-K)**
Roofs	0.273	0.259	0.259	**0.259**
Building Envelope	0.857	0.686	0.291	**0.291**
Fenestration - WWR 40%				
U-factor	6.81	5.84	1.4	**1.4**
SHGC	0.25	0.25	0.25	**0.25**
VT		0.7	0.7	**0.7**
Lighting Power Density (LPD) with Linear light control Multifamily - (w/m2-100 lux)	6	6	6	**3**

Table 8.1: Thermal conductivity of construction elements

Figure 8.5 illustrates major set of construction and sub material layers. Concrete is a popular construction material that is typically feasible compared to steel in Thailand in terms of attainability and economics.

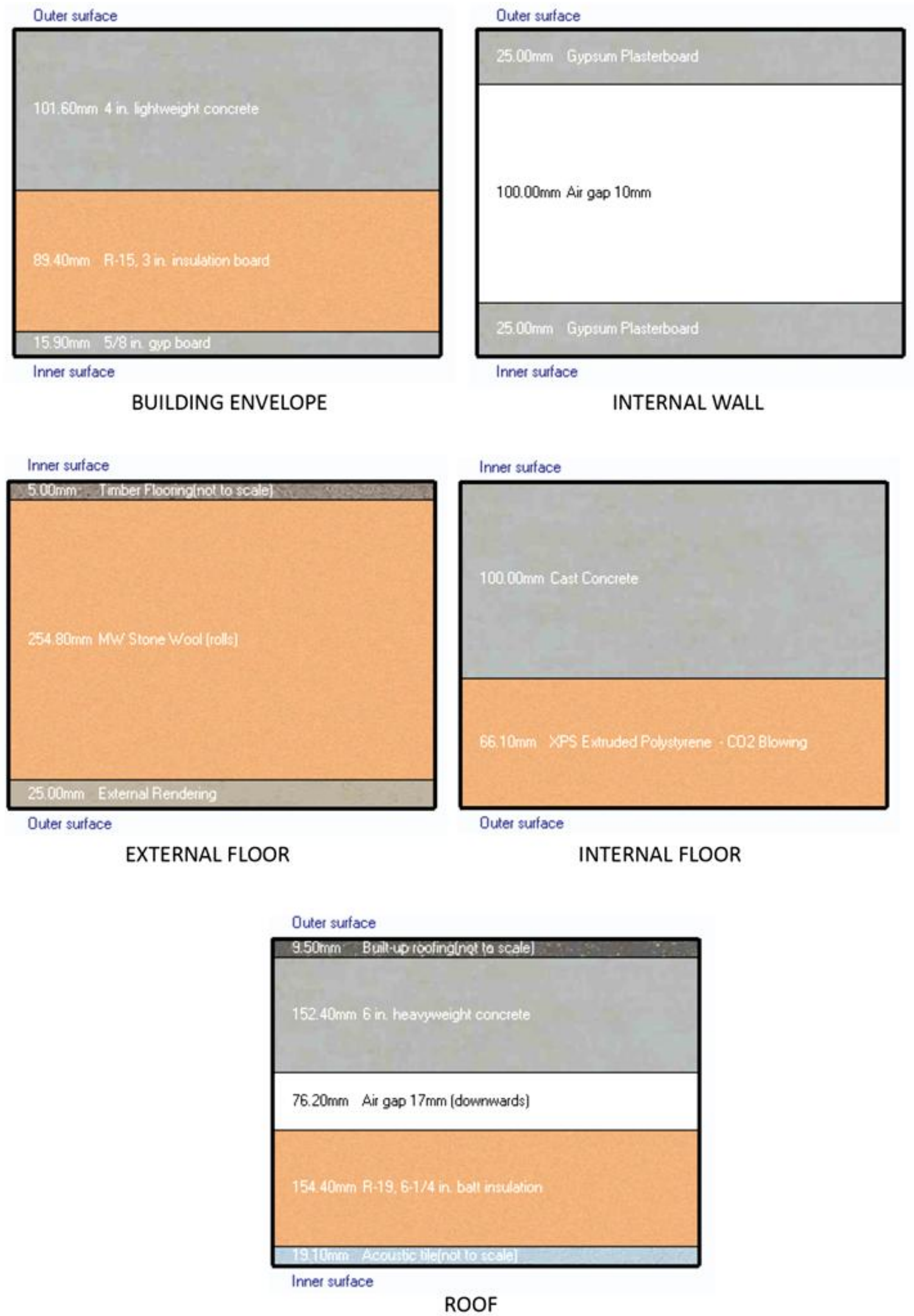
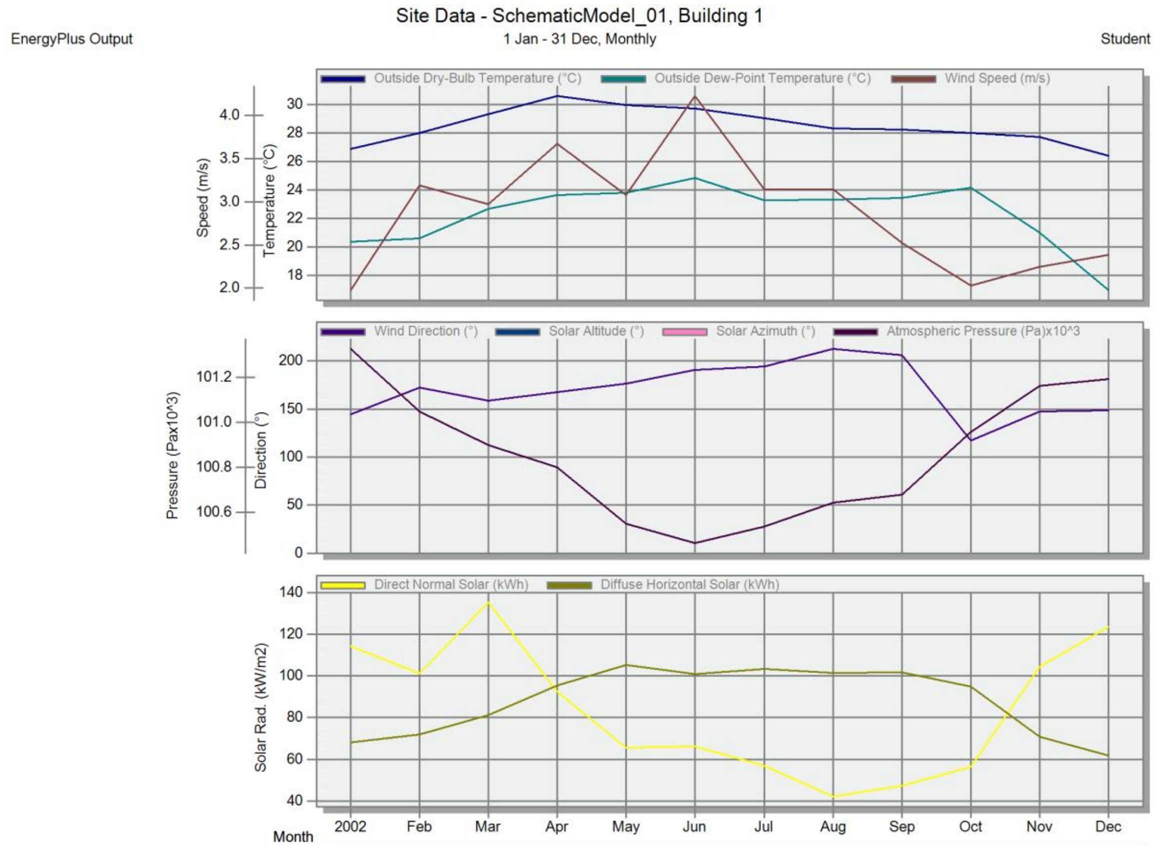


Figure 8.5: Building construction layers

8.1.3 Internal thermal comfort and internal gains study



	2002	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Outside Dry-Bulb Temperature (°C)	26.86	28.01	29.32	30.61	29.95	29.70	29.02	28.33	28.24	28.00	27.73	26.39
Outside Dew-Point Temperature (°C)	20.37	20.60	22.67	23.62	23.81	24.85	23.28	23.31	23.44	24.17	21.01	16.95
Wind Speed (m/s)	1.97	3.19	2.97	3.67	3.08	4.23	3.14	3.14	2.53	2.03	2.25	2.38
Wind Direction (°)	144.64	172.31	158.53	167.71	176.10	190.56	193.91	212.33	206.06	117.10	147.38	148.70
Solar Altitude (°)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Solar Azimuth (°)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Atmospheric Pressure (Pa)x10^3	101.33	101.05	100.90	100.80	100.55	100.46	100.54	100.64	100.68	100.96	101.16	101.19
Direct Normal Solar (kWh)	114.32	101.21	135.31	92.38	65.53	66.14	56.96	42.10	47.44	56.28	104.33	123.41
Diffuse Horizontal Solar (kWh)	68.23	71.88	81.10	95.48	105.29	100.82	103.35	101.29	101.67	94.81	70.89	61.73

Figure 8.6: Bioclimatic data
Resource: DesignBuilder annual simulation analysis

Figure 8.6 presents site conditions in Bangkok that creates problems for human comfort. Outdoor temperature range is about 27C – 31C (80.6 F- 87.8F) with April being the hottest month in the summer at about 31C (87.8F); and December being the coolest month during the winter at about 26.39C (79.50F). Wind speed in Bangkok is typically very low at about 1.97 m/s – 4.23 m/s (6.46 – 13.87 ft/sec) at ground speed. The fastest wind speed is in June at about 4.23 m/s (13.87 ft/sec) during summer season. The microclimate condition presented in the figure above will decrease the comfort performance (table 8.2) in term of fresh air temperature flow.

THERMAL COMFORT STUDY	Construction A		Construction B-1	Construction B-2
Configurations	1. Corridor (Holes)	2. From A-1 Louvers + Overhangs added	From A.2 modified Glazing	From B-1 modified LPD
Air temperature (C)	29.79	29.78	30.03	29.94
Radiant temperature (C)	30.41	30.8	30.48	30.38
Operative temperature (C)	30.1	30.08	30.25	30.16
Outside Dry-Bulb temperature (C)	29.7	29.7	29.7	29.7
Relative Humidity (%)	76.48	76.52	75.75	76.15
Discomfort hours (hr)	334.17	334.17	334.17	334.17
Franker PMV	1.3	1.29	1.38	1.35
INTERNAL GAINS				
General Lighting (kWh)	401.23	402.3	453.01	226.51
Computer+Equip (kWh)	796.82	796.82	796.82	796.82
Occupancy (kWh)	237.23	237.78	237.69	239.98
Solar Gain Exterior Window (kWh)	1779.96	1723.16	1640.68	1640.68
Total Latent load	381.71	381.16	381.25	378.96

Table 8.2: Internal thermal comfort study of different construction types in June

Assessed by consensus standard of ASHRAE standard 55, the internal thermal comfort study in table 8.2 represents the desired conditions in terms of the thermal environment. Thermal comfort is affected by heat conduction, convection, radiation and evaporation. Heat loss is determined by six primary factors that directly affect thermal comfort. These can be grouped as personal factors, such as metabolic rate and clothing level; and as environmental factors, such as air temperature, radiant temperature, air speed, and humidity. The thermal comfort study across different construction types in table 8.2 found that they are slightly different in terms of ambient air temperature, mean radiant temperature, operative temperature, humidity, and discomfort hours. However, the construction types are all in the same range of Predicted Mean Vote (PMV) trend, which appears to be slightly warm and have a tendency to become warmer. Since modifying construction properties did not make a major difference, other variables should be considered as the major influences of internal gains, including lighting loads, computer, equipments, solar gain exterior window, and latent load.

There is a possibility that there are some input variables that caused thermal comfort to behave differently. For instance, changing the lighting power density from 6 w/m2–100 lux (based on multifamily values in ASHRAE 90.1) to 3 w/m2-100 lux in construction type B-2 results in a high lighting performance. Solar gain from exterior window and total latent load are lower than previous construction sets because the conductivity of external window has been adjusted. This study was set to define variables that may affect the thermal comfort.

+ 3	Hot
+ 2	Warm
+ 1	Slightly warm
0	Neutral
– 1	Slightly cool
–2	Cool
– 3	Cold

Table 8.3: Predicted mean vote (PMV), Seven-point thermal sensation scale
Resource: ISO-7730

There are two conditions must be fulfilled to maintain thermal comfort. One is that the actual combination of skin temperature and the body's core temperature provide a sensation of thermal neutrality. The second is the fulfillment of the body's energy balance: the heat produced by the metabolism should be equal to the amount of heat lost from the body. The metabolism is the energy released by oxidation processes in the human body, which depends on the muscular activity[1]. This model is based on P.O. Fanger (Table 8.3), which represents the predicted mean vote (PMV) using a seven-point thermal sensation scale, from cold (-3) to hot (+3), that was predicted by a theoretical index for a large group of subjects when exposed to particular environmental conditions. Zero is the ideal value, representing thermal neutrality. This model was originally developed by collecting data from a large number of surveys. The participants were subjected to different conditions within a climate chamber. These data were then used to derive a mathematical model of the relationship between all the environmental and physiological factors involved. The comfort zone is defined by the combinations of the six key factors for thermal comfort where the PMV is within the recommended limits ($-0.5<PMV<+0.5$)[2]. The PMV model is calculated with the air temperature and mean radiant temperature in question, along with applicable metabolic rate, clothing insulation, air speed, and humidity. If the resulting PMV value generated by the model is within the recommended range, the conditions are within the comfort zone.

[1] LumaSense Technologies Inc. , 2012
[2] La Roche, P. ,2011

From ASHRAE standard 55, the Predicted Percentage of Dissatisfied (PPD) is related to the PMV as is defined as an index that establishes a quantitative prediction of the thermally dissatisfied people assuming that who votes -2, -3, +2 or +3 on the thermal sensation scale is dissatisfied. The model is also based on the simplification that PPD is symmetric around a neutral PM

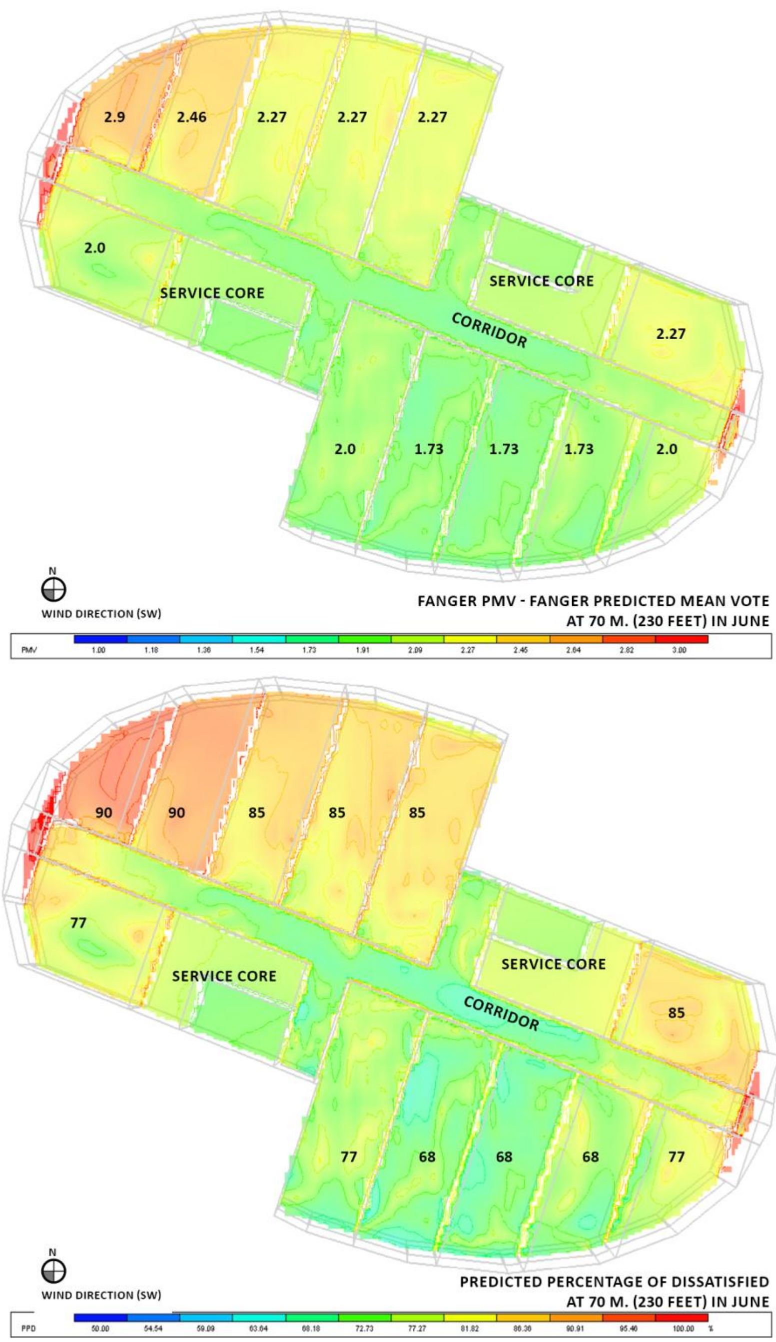


Figure 8.7: Predicted mean vote and predicted percentage of dissatisfied at 75 m. floor level in June
Resource: DesignBuilder PMV and PPD simulation

The PMV and PPD simulation in figure 8.6 is conducted on the floor level at 75 meter high during the month of June. The highest wind speeds are taken into account to observe a cross ventilation condition. The simulation results show the range of PMV is about 1.73 – 29, which are extremely high and tend to be too hot. The PPD simulation yielded predictable results. The operative temperature is high, which influences the high volume of hot air driven into the internal environment. By taking the operative temperature (OPT) and relative humidity (RH) into account, human comfort can be achieved through natural ventilation (figure 8.8).

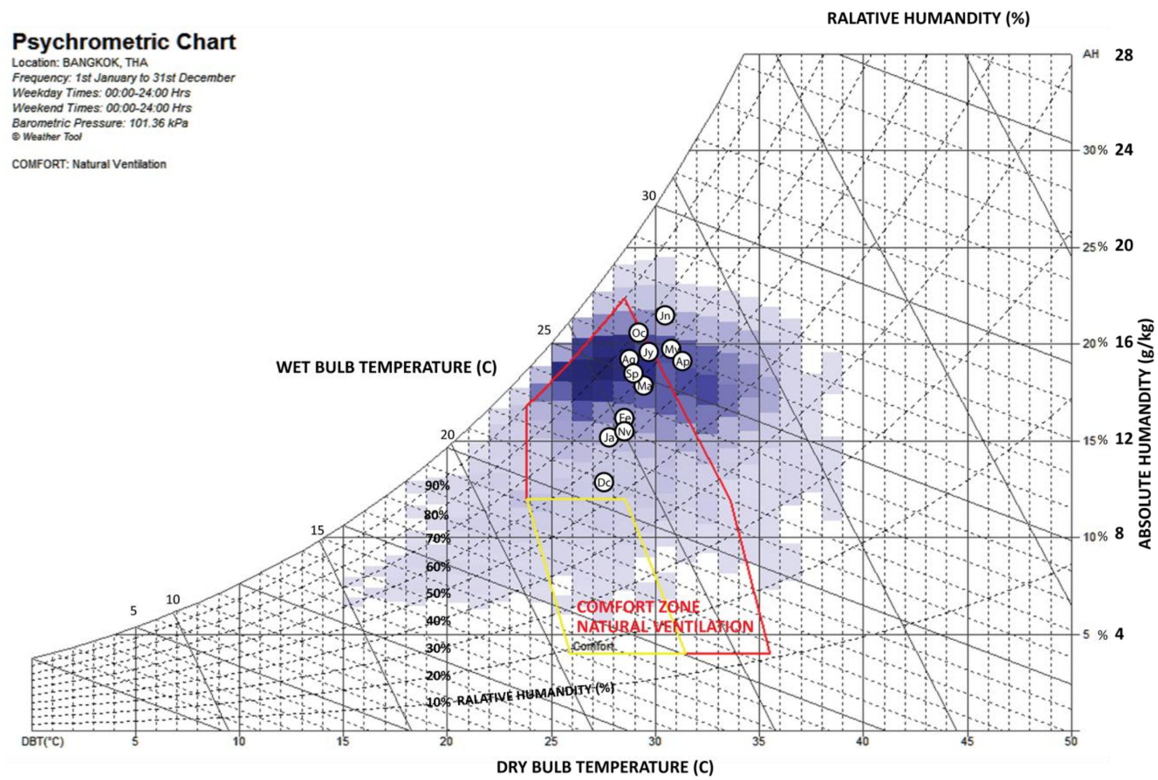


Figure 8.8: Comfort study based on the construction B in Psychrometric chart
Resource: Background graph from EcoTect weather tool

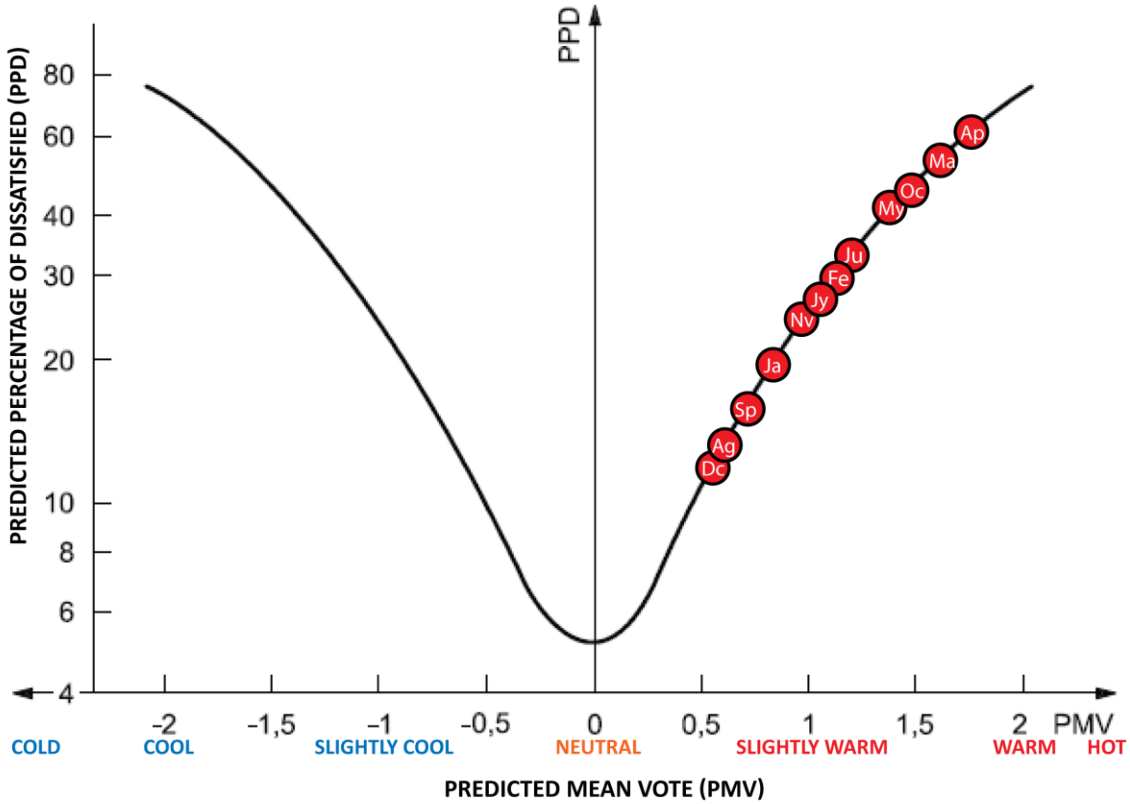


Figure 8.9: Thermal comfort study in Predicted mean vote and predicted percentage of dissatisfied graph
Resource: Background graph from ISO-7730

The psychrometric chart (figure 8.8) can be used to define the level of comfort throughout all months. In addition, scientific research aims to experiment in different model for finding the reliable performance and efficient evaluation. Figure 8.9 is a graph that shows a relationship between PMV and PPD. All months PMV values have plotted on the graph to define how many dissatisfied percentage will be in each months. The graph shows amount percentage of dissatisfied about 10 – 20% in January, August, and December which are getting slightly warm. In the other months beyond PMV 1, the percentage of dissatisfied is about 20 – 70 %. This indicates that the trend beyond PMV 1 is getting hotter. The comparative thermal comfort study based on PMV in both psychormetric chart and the PPD have proven that the percentages of dissatisfied throughout the year are high. Therefore, natural ventilation is not enough for human comfort and will require some assistant to reduce ambient air temperature and operative temperature.

8.2 Mechanical ventilation

Mechanical ventilation systems circulate fresh air using ducts and fans, rather than relying on airflow through small holes or cracks in a home's walls, roof, or windows. Mechanical space ventilation can be used to cool the building and people during times when natural ventilation forces are not sufficient. Mechanical ventilation may be used as supplement to natural ventilation for space cooling in variety of circumstances. This research has focused on the cross ventilation as the main strategy, which sometime is limited by lack of sufficient wind speeds. In areas like Bangkok with low wind speeds, there may not be enough wind velocity for passive ventilation at night.

At night, winds speeds are typically lower than during the day. Additionally, the ground level in high density areas of Bangkok has pollution and traffic noise that may make direct natural ventilation undesirable. This means that in many buildings, the use of open sections, communicating levels, or ventilation chimneys to create stack driven ventilation may not be possible. In this situation mechanical ventilation is a viable option to assist natural ventilation. Perhaps mechanical ventilation will introduce a high rate of outdoor air into buildings at a relatively low rate of energy consumption, compared to conventional air conditioning.

The thermal comfort studies in figure 8.8 and figure 8.9 reveals that cross ventilation did not cool the space enough for desired comfort. Thus, a mechanical ventilation system is needed to circulate fresh air using ducts and fans, rather than relying on airflow through vents. Without mechanical ventilation, moisture, odors, and other pollutants can build up inside the interior spaces. DesignBuilder simulates and calculates the mechanical ventilation system (figure 8.10) by taking rise in fan pressure and outdoor air changes per hour into account. Specific Fan Power (SFP) is a key variable to calculate and estimate the pressure rise. One can calculate the approximate fan pressure rise from Specific Fan Power (SFP) data using:

Delta P = 1000 * SFP * Fan total efficiency[3] ***SFP = Pe/ V***

Annex E of ISO 5801 shows that by rearranging the formula, it can be derived that the SFP is a function of fan pressure divided by the efficiency of the fan system. Therefore the SFP will increase or decrease with a respective increase or decrease in the system pressure. The SFP is a

[3] FMA, UK, 2006

function of the volume flow of the fan and the electrical power input and is quoted for a particular flow rate; ***V*** is volume flow (l/s), $\boldsymbol{P_e}$***is*** electrical power input (W) to the fan system or complete air movement installation.

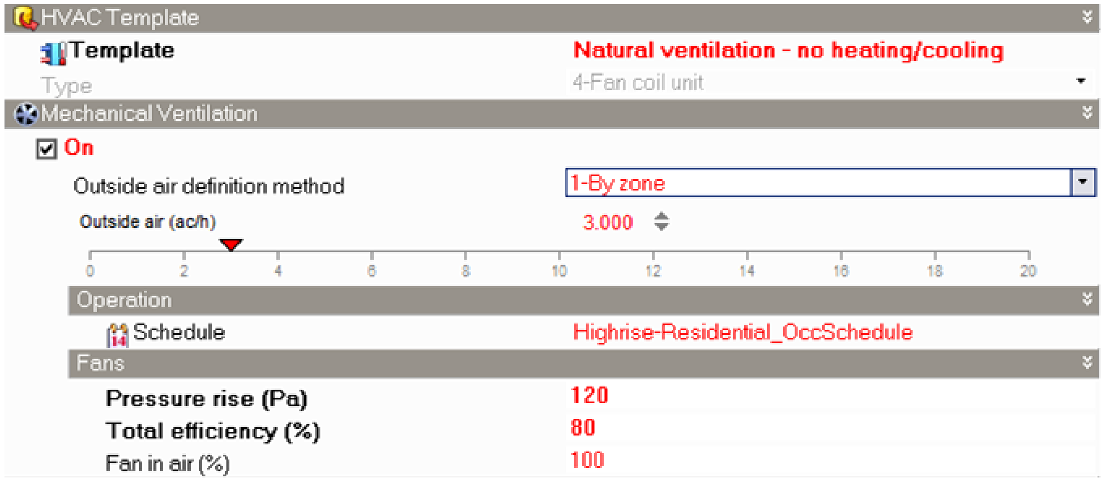


Figure 8.10: Mechanical ventilation set up interface
Resource: DesignBuilder Mechanical ventilation analysis

System Type	Specific Fan Power(W/l-s)
Central mechanical ventilation including heating, cooling and heat recovery	2.5
Central mechanical ventilation including heating and cooling	2.0
All other systems	1.8
Local ventilation units within the local area, such as window/wall/roof units, serving one room/area	0.5
Local ventilation units remote from the local area, such as ceiling void or roof mounted units, serving one room/area	1.2
Fan coil units (rating weighted average)	0.8

Table 8.4: Typical values for various system types
Resource: ESTA: http://www.esta.org.uk/

Fan total efficiency (%)

Fan total efficiency is obtained by entering the product of the fan motor and impeller efficiency of the supply fan. This is the ratio of the power delivered to the air to the electrical input power at maximum flow expressed as a percentage. The motor efficiency is the power delivered to the shaft divided by the electrical power input to the motor. The fan efficiency is power delivered to the air divided by the shaft power. The power delivered to the fluid is the mass flow rate of the air multiplied by the pressure rise divided by the air density. Must be greater than 0 and less than or equal to 100.

Fan motor in air (%)

Fan motor in the air is obtained by enter the percentage of the motor heat that is added to the air stream. A value of 0 means that the motor is completely outside of the air stream. A value of 100 means that all of the motor heat will go into the air stream, thereby, causing a temperature rise. The value must be between 0 and 100.

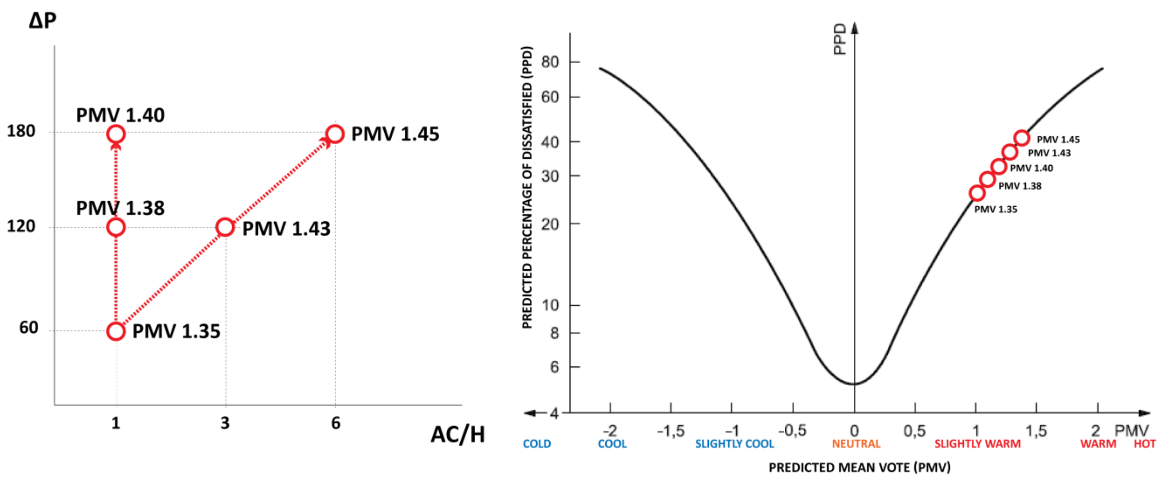


Figure 8.11: Thermal comfort study by using Mechanical ventilation
PMV performance relate to both pressure rise and air changes per hour (Left),
PMV performance on PPD and PMV graph (right)

The result of the mechanical ventilation performance (in figure 8.11) infers that an increased air change per hour (AC/H) or an adjusted pressure rise will provide a better PMV. The graph in figure 8.10 shows multiple experiments in search for an optimal PMV in various setups: either pressure rise or AC/H rise. The graphic trend reveals that the more pressure or AC/H rise, the greater the operative temperature will be. The experiment started from the lowest pressure rise about 60 parcel, which is approximately amount of pressure rise from the external pressure simulation (figure 7.22 and 7.23). The graph in figure 8.11 plotted all PMV experiment found that 25% – 60 % dissatisfied with a range of slightly warm to warm. Mechanical ventilation cannot provide a better ventilation or cool air down, because the problem is in the outside dry-bulb temperature. To achieve low PMV, it takes an applicable metabolic rate, clothing insulation, air speed, and humidity. However, the bottom line will rely on ambient temperature, mean radiant temperature, and operative temperature.

According to the ASHRAE standard 55 (figure 8.12), for operative temperatures above 25.5C (77.97F), the upper limit to air speed shall be 0.8 m/s (160 fpm) for light, primary sedentary office activities. The annual comfort study (table 8.5) shows all operative temperatures throughout the year. They are all above minimum 25.5C and typically temperature rise up to 31C which trend to be out of the comfort range.

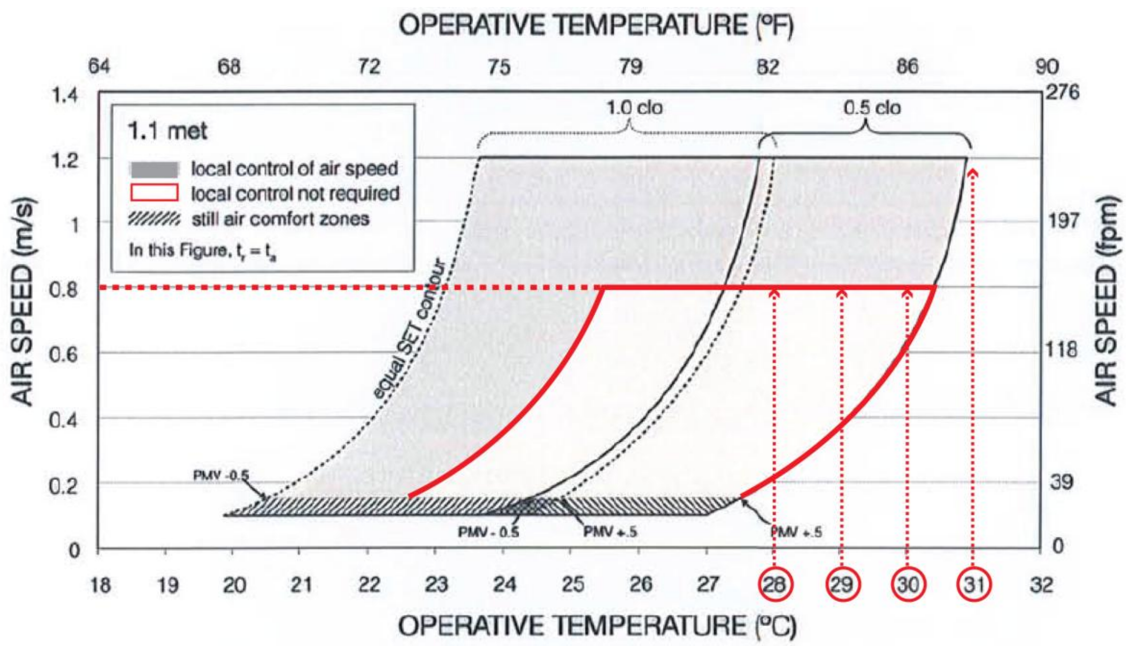


Figure 8.12: Acceptable range of operative temperature and air speeds for the comfort zone.
Resource: ASHRAE 55-2010

Month	2002	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air Temperature (°C)	27.78	28.32	29.64	30.89	30.34	29.94	29.43	28.58	28.64	28.81	28.43	27.07
Radiant Temperature (°C)	28.16	28.76	30.10	31.34	30.80	30.38	29.86	28.98	29.06	29.18	28.85	27.46
Operative Temperature (°C)	27.97	28.54	29.87	31.12	30.57	30.16	29.64	28.78	28.85	28.99	28.64	27.26
Outside Dry-Bulb Temperature (°C)	26.86	28.01	29.32	30.61	29.95	29.70	29.02	28.33	28.24	28.00	27.73	26.39
Relative Humidity (%)	65.24	65.63	68.84	67.45	69.81	76.15	71.16	74.52	75.00	77.82	65.90	55.48
Discomfort hrs (all clothing) (hrs)	274.84	298.30	343.17	321.34	330.34	334.17	330.34	336.76	327.75	330.34	311.23	218.49
Fanger PMV ()	0.95	1.13	1.63	1.70	1.46	1.35	1.04	0.67	0.70	1.44	1.18	0.60

Table 8.5: Annual comfort study on Construction B-2
Resource: DesignBuilder Simulation

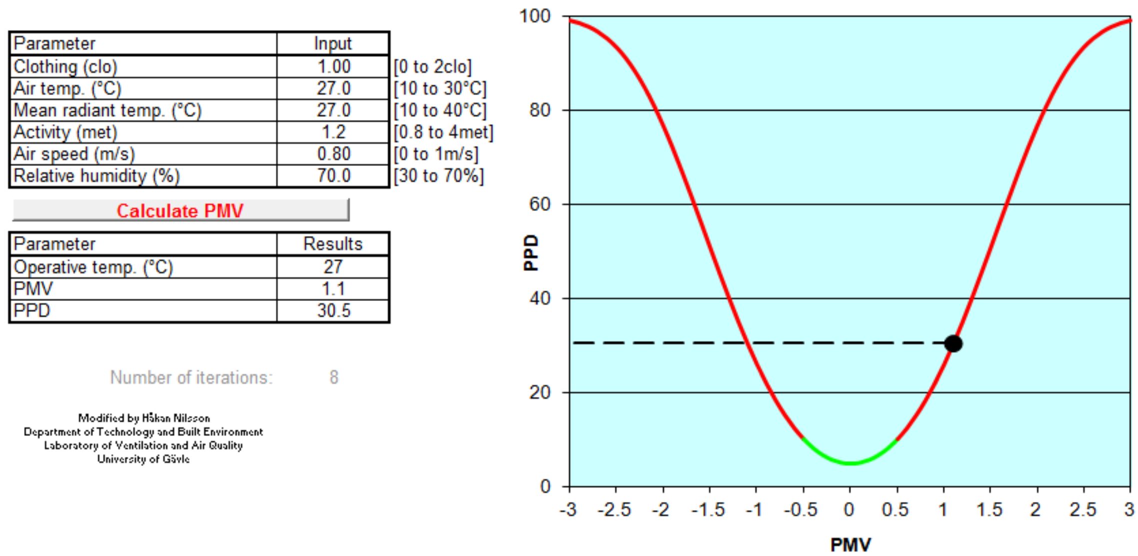


Figure 8.13: The influence factors of Predicted mean vote performance
Resource: LumaSense Technologies Inc.

The ideal of suitable PMV and PPD are based on 6 major parameters: Clothing (Clo) average about 1 clo; ambient air temperature and mean radiant temperature should not exceed than 27C– 28C; activity metabolic rate is fixed about 1.2 met[4] for specific in dwelling; air speed is limited at 0.8 m/s[5]; and lastly relative humidity is not over than 70%. Therefore the PMV will not exceed than 1.1 and PPD 31% dissatisfied. However, dropping outdoor and operative temperature below 28C – 29C will be the key primary strategies for the natural ventilation.

[4] ISO 7730, Annex B, table B.1, 2005
[5] ASHRAE 55, figure 5.2.3.2, 2010

8.3 Energy use and supply calculation

8.3.1 Energy supplies

8.3.1.1 Photovoltaic Panel (PV)

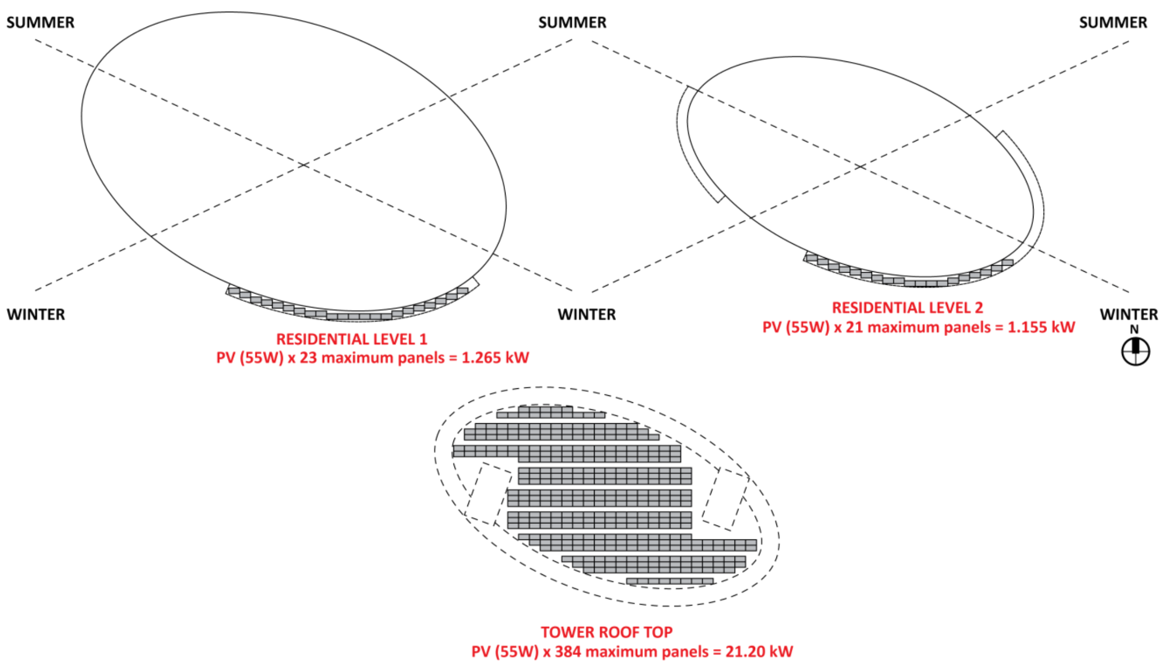


Figure 8.14: PV layout on over-hang in both residential levels and roof top

The schematic design will utilize Photovoltaic (PV) panels on the overhangs in both residential towers and on the roof top, which are about 1,100 panels for this prototype building. Panels are mounted in appropriate locations to capture solar energy (figure 8.14). The understanding of solar irradiation (figure 8.16) allows for the prediction of how much solar energy can be collected. PV panel size, dimension, and capacity are based on the local supplier in Bangkok, Bangkok Solar Company Ltd. The PV panel is using advanced Amorphous Silicon Thin Film technology (figure 8.14). BSC developed state-of-the-art a-Si Thin Film PV modules that generate more electricity than Crystalline Silicon modules with equivalent capacity. Moreover, BSC is one of the first a-Si Thin Film Photovoltaic Module certified by TÜV Rheinland on salt mist corrosion test. BSC products do not just generate more electricity at high ambient temperatures, but also produce higher energy yield under diffused and low-light conditions. So, BSC products shorten Energy Pay-Back Time (EPT) when compared with other Technologies. For all these reasons, BSC a-Si Thin Film Photovoltaic Module is the first choice among many leading companies installing solar module energy generating systems. BSC a-Si Thin Film PV modules are designed to meet international standards, customer specifications, and environment-friendly. Concerning with project IRR (Interest Rate of Return), investing in BSC solar module is a smart choice due to the fact that BSC solar module starts generating power from Sun Rise until Sun Set. BSC modules are relatively easy to install and cost-saving. BSC products have been awarded numerous certifications for quality, safety, and reliability according to its advanced production technology aligned and strict monitoring from the quality assurance system.

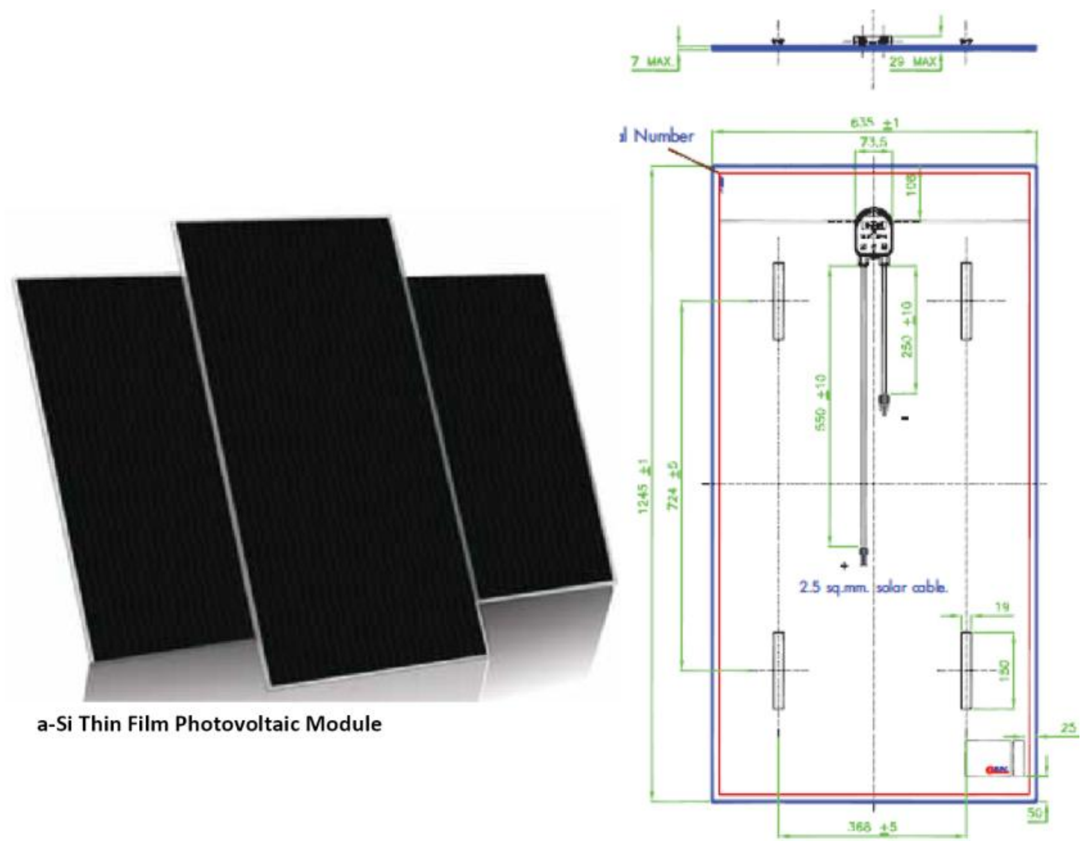


Figure 8.15: Thin Film PV product
Resource: Bangkok Solar Company Limited

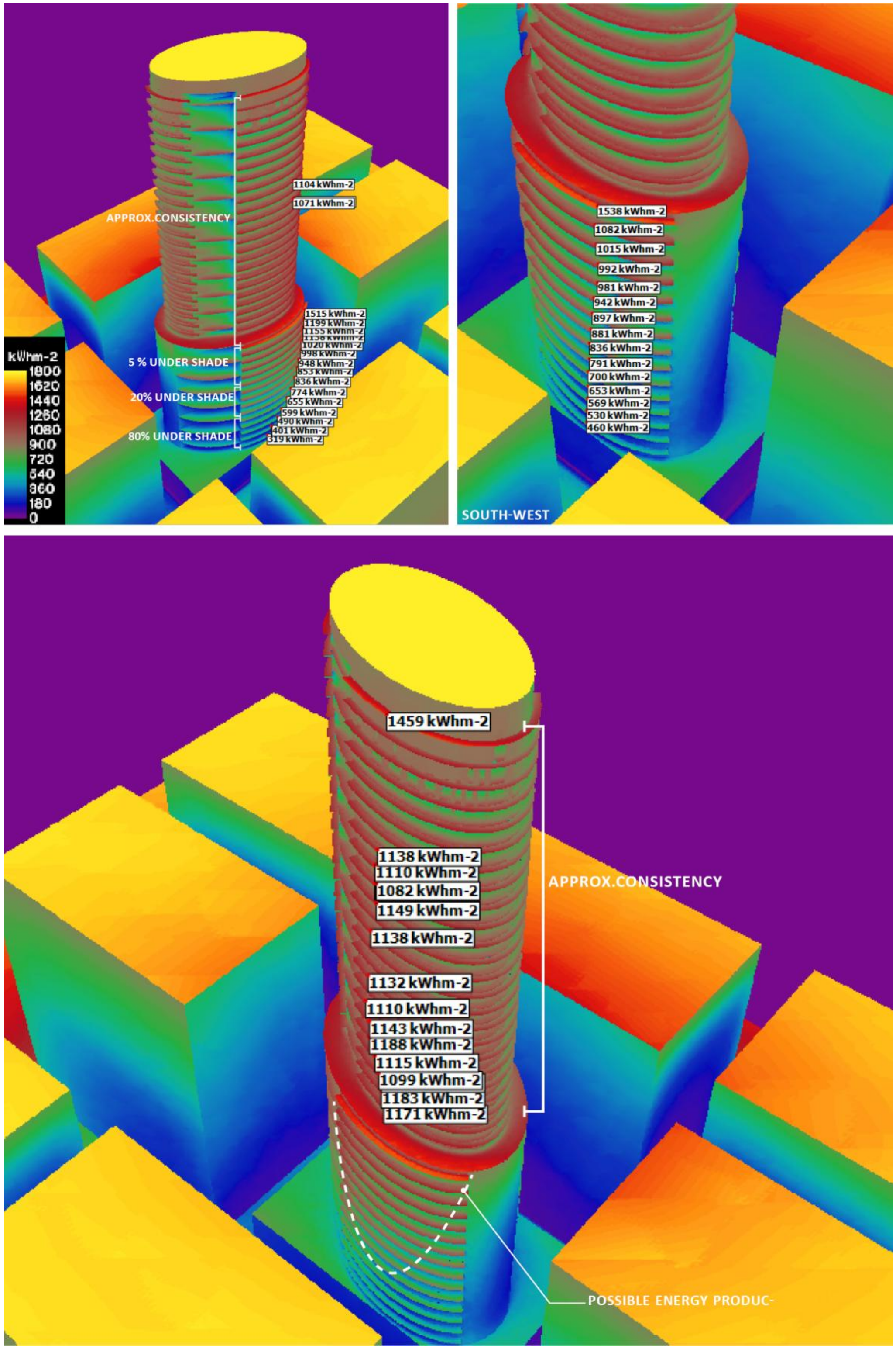


Figure 8.16: Solar Irradiation study for potential energy of PV
Resource: DIVA radiance map simulation

PV capacity

	Time period in day	% of capacity	actual power generated (kW)	energy generated (kWh)
am	12:00 to 2:00	0%	0	0
	2:00 to 4:00	0%	0	0
	4:00 to 6:00	0%	0	0
	6:00 to 8:00	10%	0.0055	0.011
	8:00 to 10:00	50%	0.0275	0.055
	10:00 to 12:00	70%	0.0385	0.077
pm	12:00 to 2:00	70%	0.0385	0.077
	2:00 to 4:00	70%	0.0385	0.077
	4:00 to 6:00	20%	0.011	0.022
	6:00 to 8:00	5%	0.00275	0.0055
	8:00 to 10:00	0%	0	0
	10:00 to 12:00	0%	0	0
			Total / day	**0.3245**
	Reference			
	Product	a-Si Thin Film Photovoltaic Module		
	Model	BS-55	Dimension = 635mm x 1245mm	
	Company	Bangkok Solar Company Limited		
	Norminal power (W)	55.0	per stall	
	Norminal power (kW)	0.055	per stall	

Table 8.6: PV capacity calculation, assumed the worst case scenario.

The Solar Irradiation study for the potential energy that PV can generate (figure 8.16) on building surfaces are used to determine a target area where PV panels will be installed for optimal solar energy. Basically PV has to be installed above the 10^{th} floor because the adjacent buildings become an obstruction of light, which make productivity inefficient. On the other hand, the PV panel can be installed anywhere on the south side of building that is above 75 meters, since there is no obstruction. Above 75 meter the solar irradiation provide a slightly consistent amount of energy. Table 8.6 shows the realistic and the worst case scenario for minimum energy production. At the same time, table 8.7 shows annual amount of electricity generated from solar energy, as well as the height where PV is installed. From one PV 55W panel will able to produce 0.3245 kWh per day. There are 1,100 PV panels including roof top will able to generate minimum 130,286.75 kWh/year (table 8.7).

PV LOCATION

PROGRAM	FLOOR	(M) F/F HT	(M) ELEV.	(stalls) PV	[kWh/day] Energy	[kWh/year] Energy
		170.75		1100	356.95	*130,286.75*
ROOM LEVEL + PARAPETS	46	4.65	170.75	384	124.61	
MEP 3	45	3.65	166.10	21	6.81	
AMENITY 2	44	3.65	162.45	21	6.81	
RESIDENTIAL LEVEL 2	43	3.65	158.80	21	6.81	
	42	3.65	155.15	21	6.81	
	41	3.65	151.50	21	6.81	
	40	3.65	147.85	21	6.81	
	39	3.65	144.20	21	6.81	
	38	3.65	140.55	21	6.81	
	37	3.65	136.90	21	6.81	
	36	3.65	133.25	21	6.81	
	35	3.65	129.60	21	6.81	
	34	3.65	125.95	21	6.81	
	33	3.65	122.30	21	6.81	
	32	3.65	118.65	21	6.81	
	31	3.65	115.00	21	6.81	
	30	3.65	111.35	21	6.81	
	29	3.65	107.70	21	6.81	
	28	3.65	104.05	21	6.81	
	27	3.65	100.40	21	6.81	
	26	3.65	96.75	21	6.81	
	25	3.65	93.10	21	6.81	
	24	3.65	89.45	21	6.81	
AMENITY 2	23	3.65	85.80	21	6.81	
MEP 2	22	3.65	82.15	23	7.46	
RESIDENTIAL LEVEL 1	21	3.65	78.50	21	6.81	
	20	3.65	74.85	21	6.81	
	19	3.65	71.20	21	6.81	
	18	3.65	67.55	21	6.81	
	17	3.65	63.90	18	5.84	
	16	3.65	60.25	18	5.84	
	15	3.65	56.60	18	5.84	
	14	3.65	52.95	18	5.84	
	13	3.65	49.30	18	5.84	
	12	3.65	45.65	18	5.84	
	11	3.65	42.00	18	5.84	
	10	3.65	38.35	inefficiency	inefficiency	
	9	3.65	34.70	inefficiency	inefficiency	
	8	3.65	31.05	inefficiency	inefficiency	
	7	3.65	27.40	inefficiency	inefficiency	
AMENITY 1	6	3.65	23.75	inefficiency	inefficiency	
MEP 1	5	4.50	20.10			
PARKING	4	3.65	15.60			
	3	3.65	11.95			
	2	3.65	8.30			
GROUND LOBBY	1	4.65	4.65			
	FLOOR	(M) F/F HT	(M) ELEV.	(stalls) PV	[kWh/day] Energy	

Table 8.7: Annual PV energy production

8.3.1.2 Vertical Axis Wind Turbine (VAWT's)

With little to no wind, Thailand is a good prospect to use turbines to power the country. Wind turbine specialist, Dr. Roy[6], asserts that 70% of the world has a low wind speeds. He is excited about the prospects for wind energy in Thailand, but insists that it must be done correctly.

Wind energy suddenly became popular after the fuel crisis in Thailand. Regular large windmills from abroad look like a monument and do not rotate until a storm comes. Low speed, decentralized wind turbines can be put anywhere, because they are small, light structures. Dr. Roy asserts that the forest is the most important thing we need to protect the forest. Destroying the forest and the fresh water to put the wind machines is not a great solution. The fact is a 10kw wind machine can be installed anywhere in Thailand. Wind machines are small enough in size (only 18 m in height) that they can be placed in front of a home, in the backyard, or even in the office. It can be a decorative feature as well as an energy producer.

Horizontal-Axis Wind Turbines (HAWTs)[7]

HAWTS has axis of rotation that is horizontal to ground and almost parallel to the wind stream. These turbines are extensively used in commercial applications to extract power from the wind. The advantages of HAWTs are the low cut-in speed, protection through furling, and ability to deliver a relatively high power coefficient. The major disadvantage of HAWTs is the location of the generator and gearbox over the tower making service and repair more complex and costly. In addition, HAWTs must face the wind for the highest productivity levels;~~ so~~ thus many of these machines require a yaw mechanism that continuously positions the turbine toward the wind.

Vertical-Axis Wind Turbines (VAWTs)[8]

VAWTs (figure 8.16-right) have an axis of rotation that is vertical to ground and almost perpendicular to the wind stream. A significant advantage of VAWTs is convenience. The generator and gearbox can be installed at ground level, which makes these turbines easy to service and repair. In addition, VAWTs can use wind from any direction and thus are suitable for locations with fast changes of wind direction.

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[6] Dr. Wirachai RoynarinSmall scale wind energy / Effects on wildlife, July 2012 http://www.thinkglobalgreen.org/windpower.html

[7] Wind Energy: Fundamentals, Resource Analysis, and Economic 2006

[8] Crystal Research Associates, LLC ; Executive Information Overview, page 21

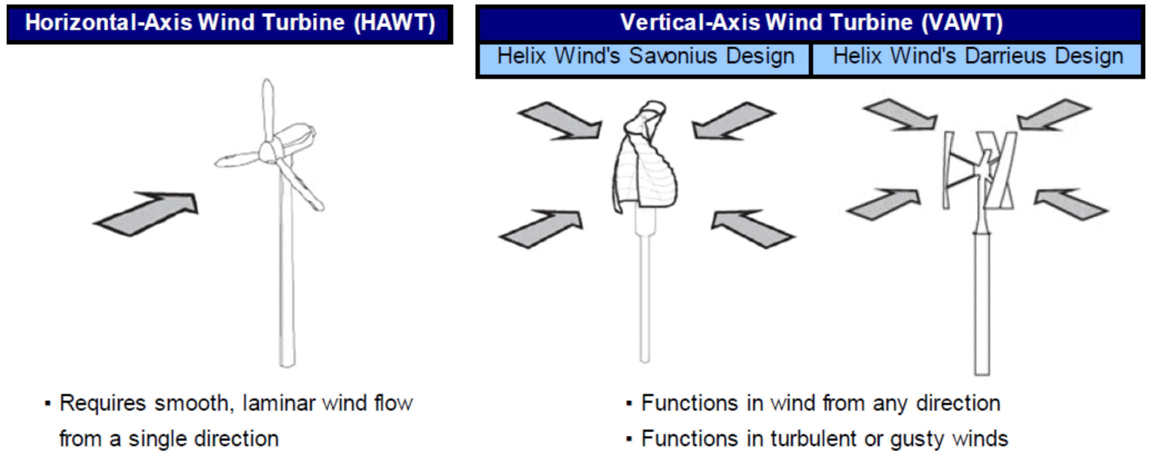


Figure 8.17: Basic Types of Turblines
Resource: Helix Wind, Corp.

Figure 8.18: The company's Savonius design-based small a wind turbines: S322 and S594
Resource: Helix Wind, Corp.

There are two VAWTs products in the schematic design that I have selected from Helix Wind: The VAWTs model S 322 which is sufficient to install at lower heights, and the VAWTs model S584 which is sufficient to install at higher positions because it able to conduct more power in the high velocity in upwind above 75 meter (table 8.8 and figure 8.18).

Savonius Turbines					
Model	kWh/yr*	Overall Height	Swept Area	Cut-in Speed**	Generator
S322 Wind Turbine	1,962	3.3 m (10.8 ft)	3.19 m^2 (34.33 ft^2)	3.6 m/s (8 mph)	2 kW High-efficiency Permanent Magnet Generator
S594 Wind Turbine	3,362	6.0 m (19.8 ft)	5.88 m^2 (63.29 ft^2)	3.6 m/s (8 mph)	4.5 kW High-efficiency Permanent Magnet Generator

** kWh/yr = Kilowatt-hours per year ** The lowest wind speed at which a wind turbine begins producing usable power.*

Table 8.8: VAWTs – S-line production specification
Resource: Helix Wind, Corp. and Crystal Research Associates, LLC

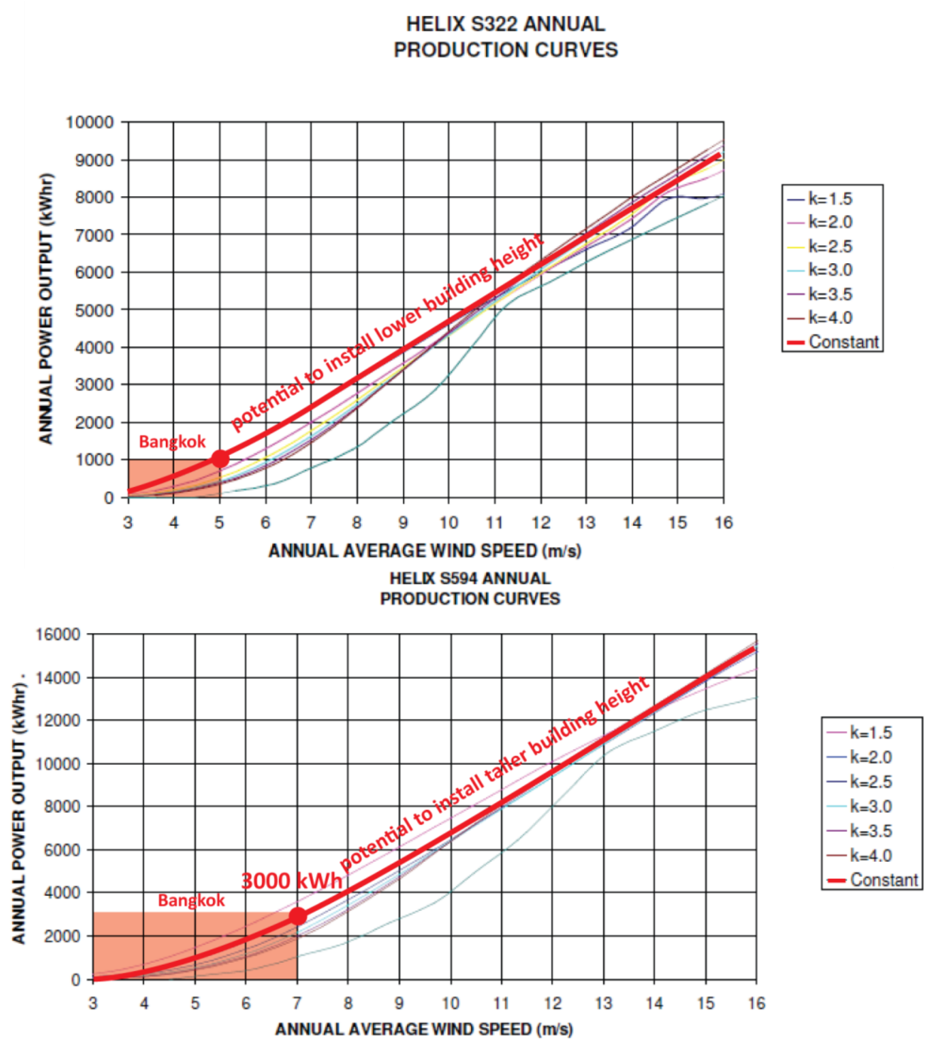


Figure 8.18: Potential power generation in different product capacity and wind speed.
Resource: Background graph based from Helix Wind, Corp. and Crystal Research Associates, LLC

VAWTs calculation			
Model	Location	(stalls) VAWTs	Possible annaul power (kWh / year)
S322	Roof garden 1	6	6,000.00
S594	Roof garden 2	4	4,000.00
S594	Highest roof level	8	24,000.00
		Total	***34,000.00***

Table 8.9: Potential annual VAWTs production
Resource: Helix Wind, Corp. and Crystal Research Associates, LLC

Applying Vertical-Axis Wind Turbines (VAWTs) has a great potential for generating renewable energy for any size of building, especially in areas of low wind speed. These products provide an alternative source of renewable energy. Installing the right model on the right place is key for optimal performance (figure 8.18). For example, installing model S322 at any level under 75 meter would provide a maximum power ~~of~~ up to 1000 kWh/ year where the average velocity is 5 m/s. Model S594, on the other hand, is a perfect fit at the higher levels where upwind velocity can speed up to 7 m/s. Under these conditions, this model is able to provide a maximum power up to 3000 kWh/year. Therefore, the VAWTs should be installed at ~~the~~ all roof garden areas and all roof tops with mechanical equipments (table 8.9). The minimum amount of wind energy will produce is 34,000 kWh / year.

8.3.2 Energy demands

	Natural Ventilation approach kWh/m2/year					Mechanical Ventilation kWh/m2/y	Air Conditioning kWh/m2/y
configurations	Construction A			Construction B-1	Construction B-2	Construction B-2	
	A1. Corridor (Holes)	A2. Louvers + Overhangs added	A3. Modified Corridor (Openings) Louvers + Overhangs	From A.3 modified Glazing	From B-1 modified LPD	-	**Based on Benchmark**
Electricity, lighting , and equipment	85.58	85.57	87.02	87.18	78.21	78.21	200
Fan assist	-	-	-	-	-	5.61	-
Total Energy demand kWh/year	**85.58**	**85.57**	**87.02**	**87.18**	***78.21***	***83.82***	***200***

Table 8.10: Summary of energy demands study

Table 8.10 summarizes how energy demand is affected by various building configurations. The natural ventilation approach has an energy demand close to 87 kWh/m^2/year, which is based on electricity, lighting loads, and equipments. By reducing the lighting power density from 6 w/m^2-100 lux to 3 w/m^2-100 lux, the energy demand dropped down to 78 kWh/m^2/year. Using mechanical ventilation will increase the energy demand by 5.61 kWh/m^2/ requiring about 84 kWh/m^2/year. In Comparison to air conditioning, with an energy demand of 200 kWh/m^2/year, mechanical ventilation requires less than half of the energy demand.

	Natural ventilation		Mechanical ventilation		Air Conditioning (Benchmark)	
	kWh/m2 /y	**kWh/year**	**kWh/m2/y**	**kWh/year**	**kWh/m2 /y**	**kWh/year**
ANNUAL ENERGY DEMAND						
Electricity + lighting + equipment	78.21	2,063,725.55	83.82	2,211,756.50	200	5,277,395.60
HVAC	-	-	-	-		
ENERGY SUPPLY						
Photovoltaic panel (PV)	-	130,286.75	-	130,286.75	-	130,286.75
Vertical Axis Wind Turbines (VAWTs)	-	34,000.00	-	34,000.00	-	34,000.00
Total energy supplies	-	164,286.75	-	164,286.75	-	164,286.75
BALANCE		***1,899,438.80***	-	***2,047,469.75***	-	***5,113,108.85***

Table 8.11: Compare annual energy demand and supplies of residential tower

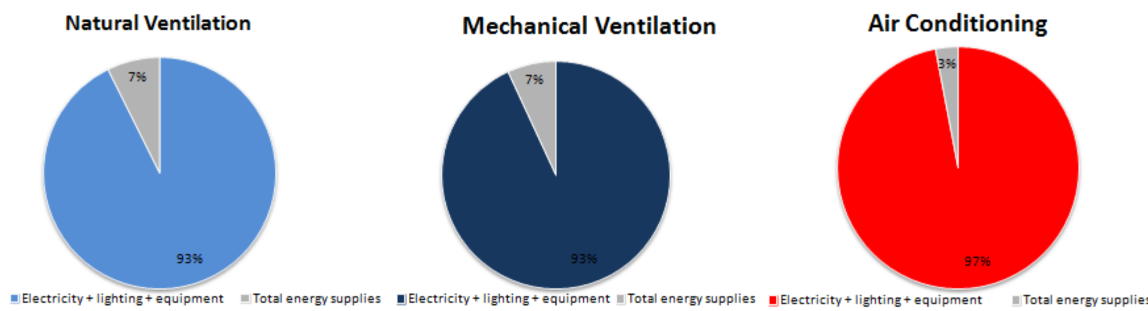


Figure 8.20: Compare energy demands and supplies in both natural and mechanical ventilation

Table 8.11 shows the comparison between energy demanded (from electricity loads, lighting loads, and equipment loads) for the residential tower, and the energy produced (from photovoltaic panels and vertical axis wind turbines). The balance shows that natural ventilation and mechanical ventilation requires about 2,063,725.55 kWh per year and 2,211,756.50 kWh per year respectively with all renewable energy sources supplying only 164,286.75 kWh per year, which is only accounts for 7% of energy needed. In comparison to an air conditioning system which has a higher energy demand (close to 5,277,395.60 kWh per year), the total renewable energy can produce only 3% of all its needs. This is a critical issue that needs to be further explored in terms of building design or alternative strategies that the productivity of renewable energy.

Chapter 9

Evaluation and Conclusion

Amid growing concerns about rising energy prices, energy independence, and the impact of climate change, buildings are considered to be the primary energy consumer in the urban setting. This fact underscores the importance of targeting building energy use as a key to decreasing the nation's energy consumption. The building sector can significantly reduce energy use by incorporating energy-efficient strategies into the design.

Pursuing a net zero energy design strategy that influences building performance and reduces it environmental impact is an aggressive research approach. However this is much needed as development of Metropolitan areas of Thailand are spinning out of control. Natural ventilation aims to take care of the cooling load in high-rise residential program. Solar energy and vertical axis wind turbines are renewable energy resources that could possibly supply all the energy needed. The previous chapters accomplished an intensive quantitative research, experiment and simulation to derive the optimum prototype design strategies. Strength of this research, beyond an aesthetically pleasing building design, is the establishment of an environmental performance based design process to enhance building science at the performance level.

The research has been based upon computational fluid dynamic (CFD) which focused on wind driven forces in both pressure distribution and velocity on different building geometries. The CFD methodology was able to define potential cross ventilation in a schematic design. The research addressed how to balance passive ventilation with optimal internal thermal comfort. This chapter will evaluate and conclude all process methodologies. There are three major questions that will lead the chapter discussion into a critical evaluation and conclusion:

1. What is the result of design performance? How is proposed design meeting a benchmark? What are significant of proposed benchmark contribute to the environment?
2. Is there a possibility to establish a net zero energy building design in Bangkok? How much opportunity of natural energy resources can be part of design integration? How can a net zero energy design successfully meet human comfort?
3. Can the design process and strategies in this thesis be evaluated? What are some further suggestions to push this research forward?

9.1 Meet the benchmark

Category	Existing Performance	Benchmark Approach	Natural ventilation	Mechanical ventilation
Energy Intensity electricity for Residential (Based on EEDP)[1]	256 KWh/m^2/Year	HEPs (High Performance Standard) about 200 kWh/m^2/year	***78.21 kWh/m^2/year***	***83.82 kWh/m^2/year***
Retails[2]	370 KWh/m^2/Year	HEPs (High Performance Standard) 266 kWh/m^2/year	Adopted and Referred	
Water consumption[3]	89.81 gallons/capita/ day	Capture 5% of total used, 4.5 gallons /capita/ day during 12 months	4.5 gallons/ capita/year	
Green Space (Based on Asian Green City Index), ASA, Law and Regulation	30 sqft./ person OSR[4] require 3% of total floor area	Open Space and Green space 10% (70-80 sqft/ person)	6,444.08 m^2 (16% of total area)	
Parking space	60 – 80% for condominium grade B[5]	50% parking stalls	200 stalls (67%) of 300 stalls (100%)	

Table 9.1: Summary of actual design performance against benchmark approaches

The predicted energy demanded of residential tower in both natural ventilation and mechanical ventilation are at least 2 times less than a benchmark, because there was no cooling load has been applied (table 9.1). Although the HEPs (High Performance Standard) from the benchmark perform better than the existing load, it still required a cooling load and energy demand that was 2.5 times the amount of natural ventilation. Commercial retail energy performance is not a part of calculation. Unfortunately, there is a limitation of space that was able to capture rain water with only 5% of possible space used. Green spaces and open spaces composed of 16 % of total gross floor area (GFA) because the podium and inset geometry provided multiple green roof areas. The economical parking structure was designed to minimize floor slabs and maximize parking stalls up to 200 stalls, which is about 67% of total required stalls.

[1] Ministry of Energy, Thailand 20-Year Energy Efficiency Development Plan 2011-2030
[2] Ministry of Energy, Thailand 20-Year Energy Efficiency Development Plan 2011-2030
[3] Asian Green City Index, Economist Intelligence Unit 2011
[4] Architect Siam Association (ASA), Law and regulation
[5] Colliers International Thailand scrutinizes every condominium project in Bangkok and provides a grade based on the criteria table 5.1

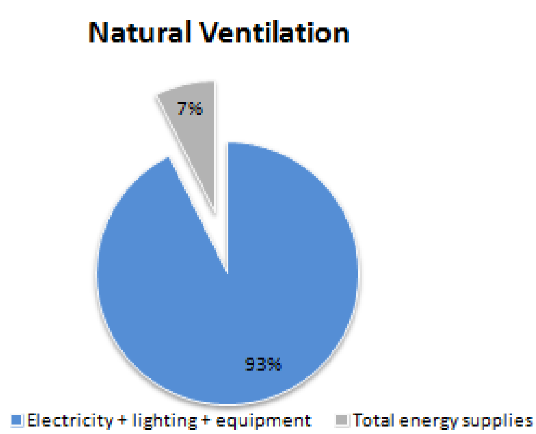
9.2 Possible Net zero energy

9.2.1 Balance energy demand and supply

	Natural ventilation kWh/year	**Mechanical ventilation** kWh/year	**Air Conditioning (Benchmark)** kWh/year
ENERGY DEMAND	2,063,725.55	2,211,756.50	5,277,395.60
ENERGY SUPPLY	164,286.75	164,286.75	164,286.75
BALANCE	***1,899,438.80***	***2,047,469.75***	***5,113,108.85***

Table 9.2: Compare annual energy demand and supply of residential tower

Natural ventilation and Mechanical ventilation are using fresh air from outside to inside without a cooling load in the building system, saving a large amount of energy. The major energy demands are based on the electricity loads, lighting loads, and equipment loads and the additional fan loads for mechanical ventilation. However, the photovoltaic panels and vertical axis wind turbines are capable of supplying some of the extra energy demand (more details in table 8.11, chapter 8). The renewable energy resources produced over 160,000 kWh/ year, which was only able to supply 7% of total energy demand, 2 million kWh/year (table 9.2 and figure 9.1).



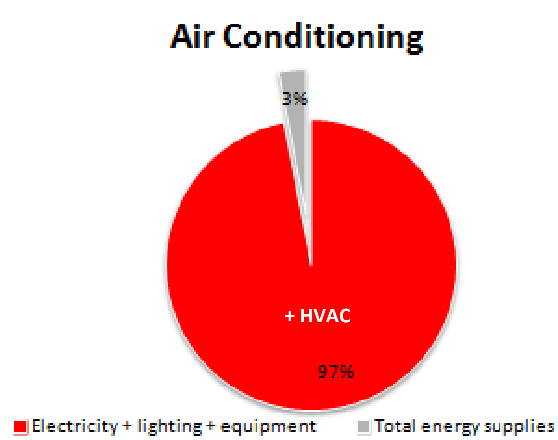


Figure 9.1: Compare energy demands and supplies in both natural ventilation and air conditioning

9.3 Thermal comfort projection

<u>9.3.1 Compare the energy performance and thermal comfort differs to different strategies</u>

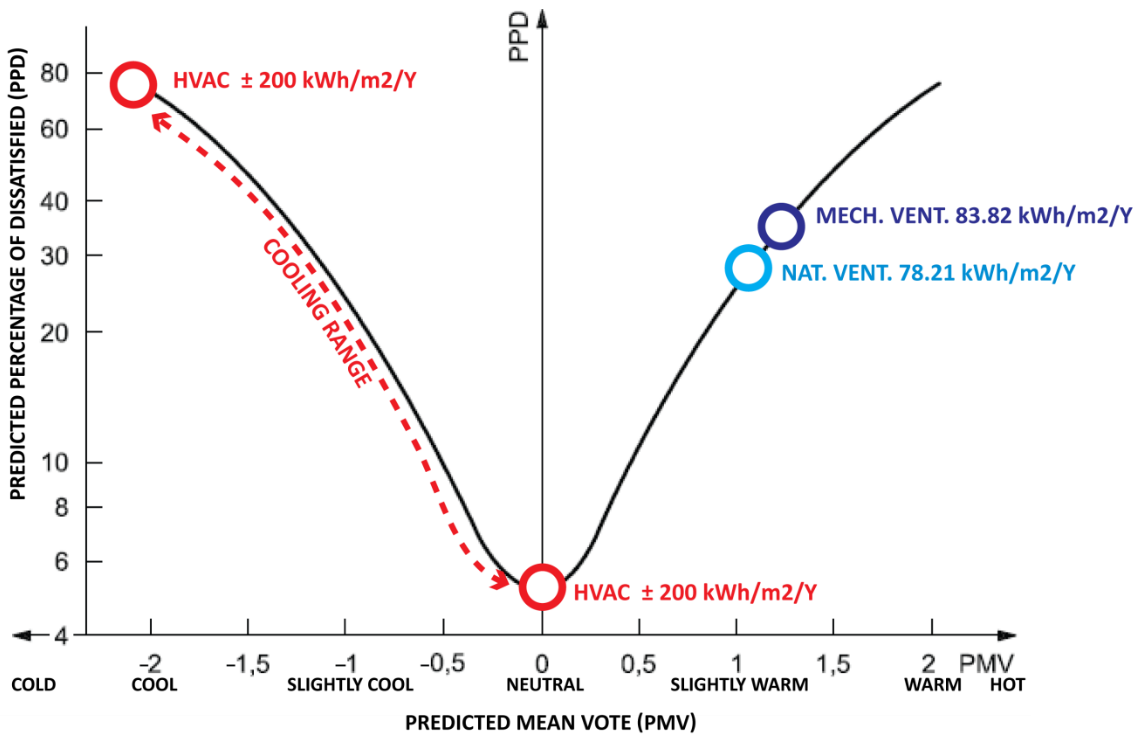


Figure 9.2: Correlation between energy demands on different ventilations and thermal comfort
Resource: Background graph from ISO-7730, 2005

The research found that natural ventilation could not provide an adequate comfort level throughout the year, except in December and January. Discomfort hours are over 40% of total hours in a year (table 8.5). Analyzing the internal thermal comfort with the psychometric chart and PMV- PPD graph did not support the sole use of cross ventilation within the contextual condition of Bangkok (as it shown in figure 8.7 and 8.8). The application of mechanical ventilation to improve indoor air quality did not yield better results than that of natural ventilation (figure 8.10). Figure 9.2 shows a correlation between energy demand on different ventilations and thermal comfort based on subject performance. Although both natural and mechanical ventilation required less energy than the air conditioning system, they still could not get close to the neutral point of PMV leaving the dissatisfied percentage high. On another hand, air conditioning systems consume high energy to achieve a cool temperature, which range of comfort will start from 0 to -2 or neutral to cold, depending on the efficiency of cooling system.

9.3.2 Establish local thermal comfort

Fanger's comfort model was the first to develop the Predicted Mean Vote (PMV) model and the Predicted Percentage Dissatisfied (PPD) in the 1970's from laboratory and climate chamber studies at Kansas State University of United Stated and the Technical University of Denmark. In these studies, participants were dressed in standardized clothing and completed standardized activities, while exposed to different thermal environments, and participants recorded how hot or cold they felt, using the seven-point ASHRAE thermal sensation scale. He extracted correlations which influence the condition of thermal comfort from the 1,300 subjects[6] at KSU and Denmark in response to the variables. Fanger's model is based upon an energy analysis that takes into account all the modes of energy loss from the body, including the convection and radiant heat loss from the outer surface of the clothing, the heat loss by water vapor diffusion through the skin, the heat loss by evaporation of sweat from the skin surface, the latent and dry respiration heat loss and the heat transfer from the skin to the outer surface of the clothing. In essence, the PMV Model combines physical variables (such as air temperature, air velocity, mean radiant temperature, and relative humidity), and personal variables (such as clothing insulation and activity level) into an index that can be used to predict the average thermal sensation of a large group of people. Fanger extended the PMV to a related index which account for dissatisfaction levels called the Predicted Percentage Dissatisfied (PPD). This index is calculated from PMV, and predicts the percentage of people who are likely to be dissatisfied with a given thermal environment. A person's dissatisfaction is defined in terms of their comfort vote. Those who voted outside the central three scaling points on the ASHRAE 55, 2010 scale were counted as dissatisfied. The distribution of PPD is based on observations from climate chamber experiments and not from field measurements. The PMV and PPD form a U-shaped relationship, where percentage dissatisfied increases for PMV values above and below zero (thermally neutral).

However, PMV predictions based on the static model[7] as well as PPD is a quantitative prediction of the thermally dissatisfied people within certain area, where Fanger's comfort model was related subjects. The PMV model is designed to predict the average thermal sensation for a large group of people. Even if the thermal environment in a space is maintained

[6] Bjarne W. Olesen, Denmark
[7] ASHRAE Standard 55, 2010

in accordance with the PMV model, there will be some occupants who are thermally uncomfortable. These differences between people are acknowledged by Fanger, which is reflected in the PPD index. Urbanization in tropical metropolitans, such as Bangkok Thailand, the rise in thermal sensation surpasses the limits of thermal comfort, which is largely due to the urban heat island (UHI) and the large influx of people to the city. Other environmental conditions that contribute to this rise in outdoor temperature include: few trees and vegetation to block solar radiation or to carry out evapotranspiration; low reflective built surfaces that absorb great amounts of heat; air conditioning systems generating heat outside as they cool down interior space; and automobiles generating heat from their engines and exhaust.

People in the city are experiencing and adapting into local climate. Therefore, the adaptive model[8] considers the relationship between indoor comfort and outdoor local climate, taking into account that humans can adapt and tolerate different temperatures during different times of the year. The adaptive hypothesis predicts that contextual factors and past thermal history modify building occupants' thermal expectations and preferences. Field studies are demanded and performed in these areas to see what the majority of people would prefer as their set-point temperature indoors at different times of the year.

Thus it is possible to establish a shifting comfort zone to a new dimension for thermal comfort study, especially in the contexts of contemporary tropical architecture and vernacular environments.[9] A field study of thermal comfort was conducted by Kitchai Jitkhajornwanich at Faculty of Architecture, Silpakorn University Thailand. During hot and rainy seasons in 2003 there were 1,322 subjects in the surveys where is hot-humid vernacular environments of Thailand. All subjects were free to wear any clothes, do any activities, and adapt to secure their comfort, according to their norm of daily living. The result from analysis found that there was a good relationship between comfort and climate, although the thermal conditions in the study were relatively extreme. A new comfort zone can be established, comparing with the classic Olgyay's (1963) comfort zone. Environmental factors that had been measured and recorded were air temperature (Ta), relative humidity (RH) and air velocity (V). These factors were taken the measurement by digital instruments of a hygrometer and an air velocity meter. The physical data in table 9.3 describes the total sample of respondents with 1,322 people surveyed for 22

[8] ASHRAE Standard 55, 2010
[9] Jitkhajornwanich, Kitchai , PLEA2006

days during hot season (March and April) and rainy season (May and October) in 2003. The surveys were conducted during 9-10 in the morning and 4-6 in the evening. All were in the vernacular contexts. The age of the sample group ranged from under 20 to over 60 years, with majority of 65% were over 40 years. There were 61% females and 39% males.

Parameter	Min.	Max.	Mean
Clothing insulation (clo)	0.13	0.70	0.29
Metabolic rate (met)	0.80	2.00	1.20
Air temperature (°C)	26.8	39.2	33.2
Relative humidity (%)	41.8	90.0	59.6
Air velocity (m/s)	0.01	4.64	0.35

Table 9.3: Summary of the profiles of physical data from surveys
Resource: Kitchai Jitkhajornwanich, PLEA2006

In figure 9.3, the surveys resulted shows in the comparative study that applying the new comfort zone had been tested against the central-three-category of ASHRAE Scale. Figure 9.3 depicts the application of the central-three-category ASHRAE Scale on Olgyay's Bioclimatic chart. The comparison indicated that no votes overlapped whit Olgyay's comfort zone, while there were a large number of votes in the proposed comfort zone.

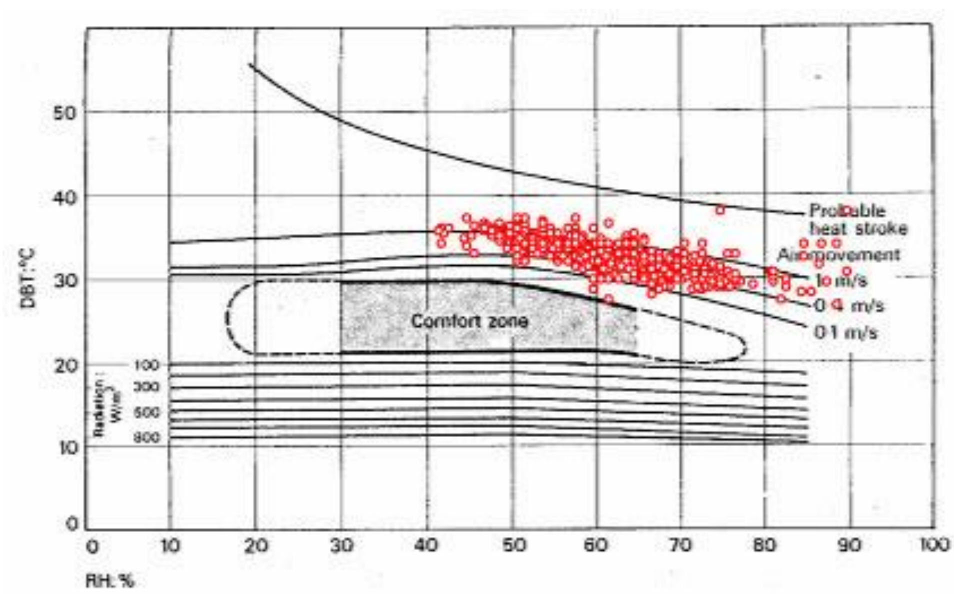


Figure 9.3: The central-three-category of ASHRAE votes applying on Olgyay's Bioclimatic chart.
Resource: Kitchai Jitkhajornwanich, PLEA2006

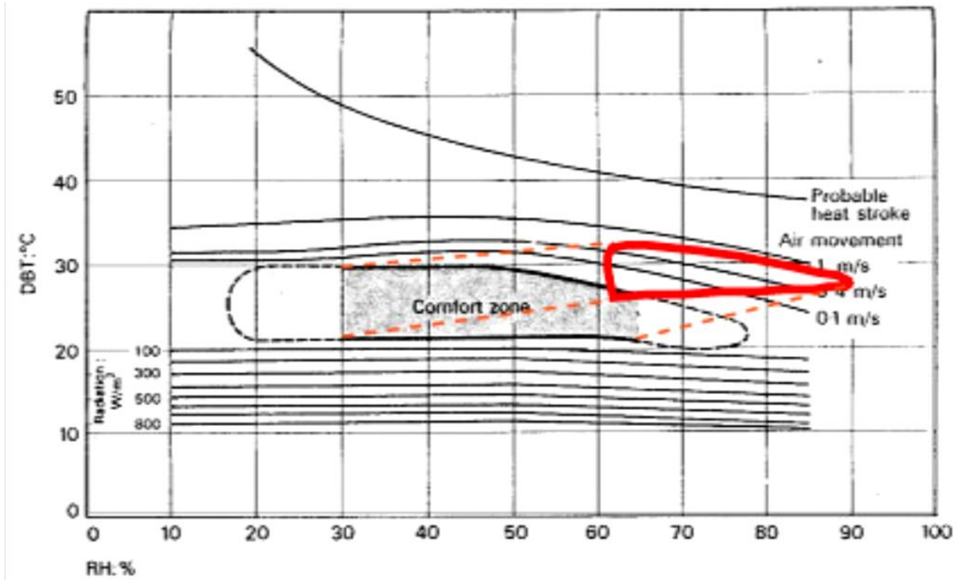


Figure 9.4: The proposed comfort zone shifting from the Olgyay's Bioclimatic chart.
Resource: Kitchai Jitkhajornwanich, PLEA2006

Therefore, in figure 9.4 the classic Olgyay's comfort zone (air temperatures of 21-30°C and relative humidities of 35-65%) can be shifted into a new comfort zone (air temperatures of 25.6-31.5°C and 62.2-90.0%). Although the Kitchai's surveys focused on the vernacular environment, the conditions were not as extreme as the metropolis of Bangkok.

Thus, Bangkok possibly has a better thermal adaption and behavior adjustment from Farger's comfort model in a higher temperature and higher humidity range due to high levels of local climate tolerance. The thermal comfort on prototypical model analysis (figure 9.2) in both natural ventilation (PMV +1.1 and PPD 30%) and mechanical ventilation (PMV + 1.4 and PPD 40%) are in the range of slightly warm to warm that can be fit into a new comfort model (Kitchai, 2003).

9.4 Forecast

9.4.1 Cool down air temperature

The high level of the operative temperature (table 8.2) was the main reason that the natural ventilation did not provide enough comfort level for the internal environment. In addition, the outdoor has a dry bulb condition throughout the year (table 8.5), which is up to 30.61C (87.08F), causing an operative temperature of 31.12C (88F). It was over the limit for the comfort zone when measured against the baseline velocity of 0.8m/s (160 fpm). An operative temperature should exceed the temperature of 30C (figure 8.11) for comfort. The only way to lower the PMV and the PPD is to cool down the ambient air temperature and the mean radiant temperature before ventilating to the internal space.

In addition, the proposed green roof and vertical green wall can possibly provide a significant reduction in outdoor temperature. Evaptranspiration by trees absorb CO2 and realease water vapor into the air, while other forms of vegetation can reduce the urban heat island effect. A recent study of the Casa de Pilatos in Seville, Spain, indicates that in summer, temperature differences of up to 10C occur between green courtyards and dry paved courtyards[10]. Moreover, the Solar Reflectance Index (SRI)[11] is used to determine the effect of the reflectance and emittance on the surface temperature, and varies from 100 for a standard white surface to zero for a standard black surface. The SRI is calculated using ASTM E1980, "Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low-Sloped Opaque Surfaces."[12] Materials with the highest SRI are the coolest and the most appropriate choice for mitigating the heat island effect.

9.4.2 Review natural ventilation strategies

9.4.2.1 Cross ventilation with double loads

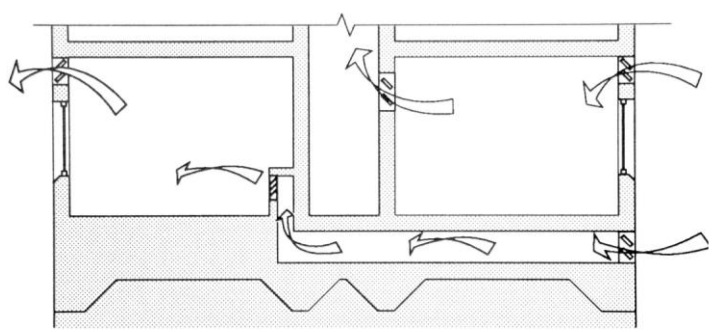


Figure 9.5: Duct supply
Resource: Nick Baker: Research Associate, The Martin Centre, University of Cambridge

Cross ventilation can be achieved with openings in the corridor partition, but is generally unsatisfactory since the ventilation of the leeward room, relies on the occupant of the windward room. The openings would also present acoustic and hygienic problems in this type of

[10] PHDC Press, 2010
[11] Lawrence Berkeley National Laboratory, 2001
[12] Lawrence Berkeley National Laboratory, 2001

residential building. The solution is to provide a bypass route, which pressurizes the corridor with fresh air, and allows independent control to the occupant of the leeward room. The duct could be within a ceiling zone, or a useable annex to the circulation space, between two windward rooms. There are many variables that may in contribute to a weak cross ventilation performance. Nevertheless, cross ventilation remains the primary strategy as the urban heat island effect raises outside temperature.

Ventilation configurations	Depth to floor/ceiling ht H.
single sided, single opening	1.5 H
single sided, multiple opening	2.5 H
cross ventilation	5 H

Table 9.4: Ventilation Configurations
Resource: Nick Baker: Research Associate, The Martin Centre, University of Cambridge

9.4.2.2 Wind induced supply and/or extract by stack

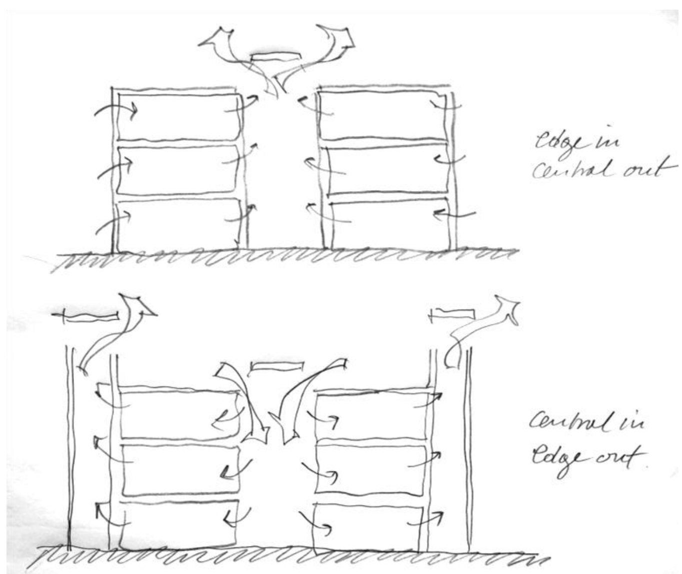


Figure 9.6: Wind induced supply and/ or extract by stack
Resource: Nick Baker: Research Associate, The Martin Centre, University of Cambridge

Wind induced supply generally suits deeper buildings. It is almost always used in conjunction with the thermally induced stack effect. Two subtypes can be identified. First from the centre to the edge outlets, where the air intake is usually passing through an atrium and the outlet is by stacks or windows on the perimeter (figure 9.6 top). Second, from the edge to the center inlets, is where the stack is used as extract, drawing air in from openings in the perimeter (figure 9.6

below). In both types, the stack effect, and the wind-induced (suction) pressure cooperates to extract air from the building. Stacking effect allows natural ventilation to travel vertically, either in or out from edge. This strategy, however, does not guarantee a cool interior space because hot air is sometimes drawn into the living area.

9.4.2.3 Passive downdraught cooling[13]

A passive down-draught evaporative cooling system is a passive evaporative cooling technology that is designed to capture the wind at the top of a tower and cool the outside air using water evaporation before delivering the cooled and humidified outside air to a space (figure 9.7). It relies on the effect of gravity on the body of cold air to create a downdraught and circulate air from the source. Thus, it can provide cooling without significant energy use and can also produce a better indoor environment by providing fresh, cool air into a space. This strategy has been accomplished in Southern Europe that provides a great significant reduce the cooling load. In residential buildings the cooling load can be reduced to well below 15 kWh/m^2 per year.

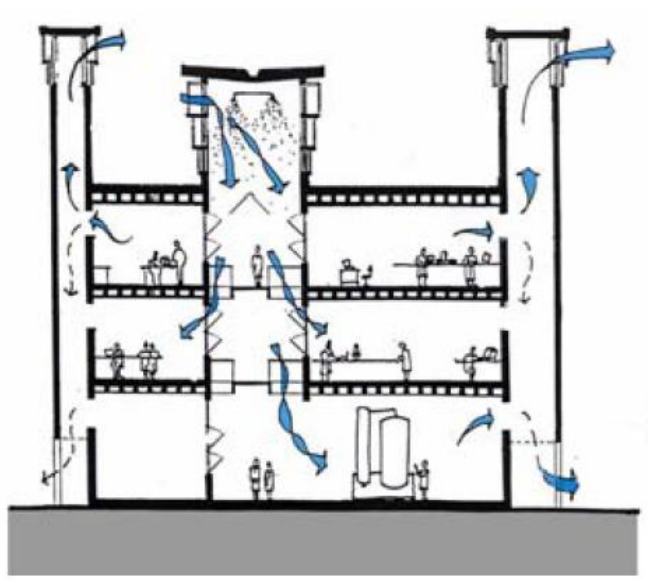


Figure 9.7: Wind induced supply and/ or extract by stack
Resource: PHDC Press, 2010

[13] PHDC Press, 2010

The tradition of cooling with air conditioning which incorporates a range of deign responses to climate, has its original in ancient Egypt and hot dry condition. Nevertheless in Bangkok climate is a hot and humid condition where the humidity ratio can be up to 90%. Downdraught cooling strategy can lower air temperature before it enters into the occupied zone; however, it will pick moisture in the air, and increase humidity in an already humid climate.

9.3.3 Maximize on-site renewable energy

In 8.3 Energy use and supply calculation of Chapter 8, there are two majors' renewable supplies: the vertical-axis wind turbine and the photovoltaic panel. The summary of energy supply calculation (figure 9.3) can provide only 5% - 7% of energy demanded. In order to balance the energy needed to operate the building, all strategies for renewable energy must be capitalized. Over the last two decades, photovoltaic systems (PV) have evolved rapidly and proved to be an efficient system and practical solution for the sustainable supply of energy in buildings. Because it converts solar energy to electricity, it has a huge potential for renewable energy for skyscrapers.

PV technology is a viable source of energy with a performance range from (50-55 W/m^2)[14] of the PV area depending upon the type of cell, specifically, how well it transmits daylight. The application of PV panels can be significant for high-rise buildings. Being one of the tallest buildings in an urban setting allows for maximum sun exposure for the PV panels, as well as greater opportunity for diffused light.

[14] Nominal power (W) per stall in Chapter 8, table 8.6

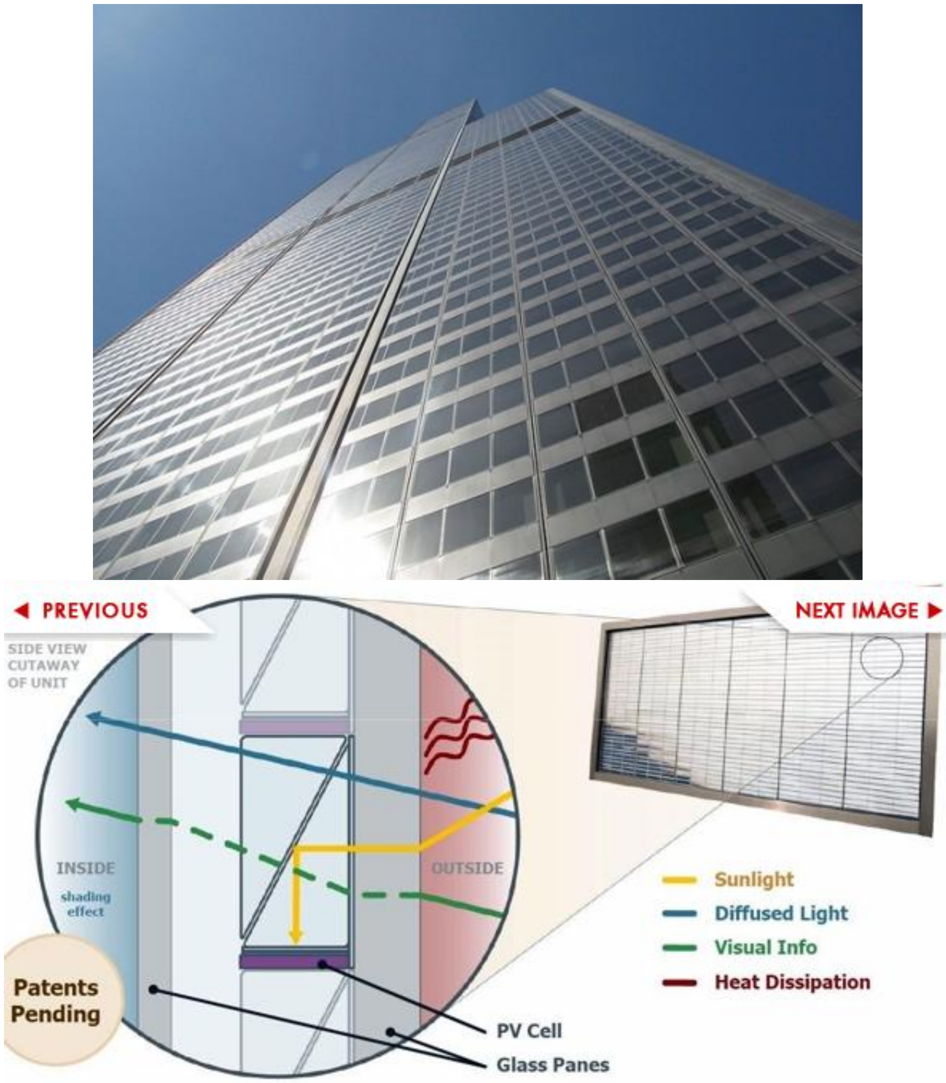


Figure 9.8: Chicago's Willis Tower to Become a Vertical Solar Farm
Resource: Andrew Michler, 2011

Example in figure 9.8, Chicago's iconic Willis Tower[15] (formally the Sears Tower) is set to become a massive solar electric plant with the installation of a pilot solar electric glass project. The high-profile project on the south side of the 56th floor will replace the windows with a new type of photovoltaic glass developed by Pythagoras Solar; which preserves daylighting and views, reduce heat gain and at the same time produce the same energy as a conventional solar panel. The project could grow to 2 MW in size which is comparable to a 10 acre field of solar panels, thereby turning North America's tallest building into a huge urban vertical solar farm.

[15] Inhabitat - Sustainable Design Innovation, Eco Architecture, Green Building, 2011

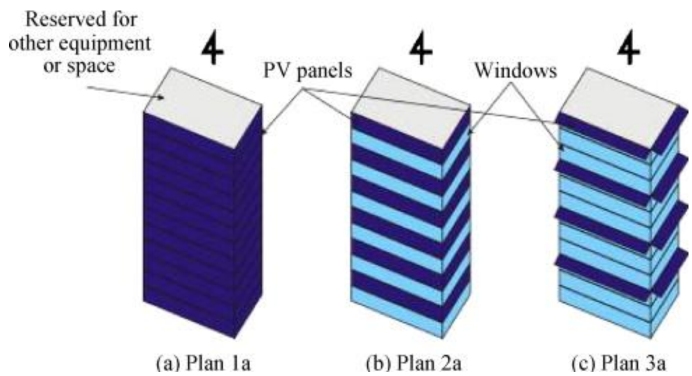


Figure 9.9: Schematic diagrams of the attachment plans for high-rise building.
Resource: Taeyon Hwanga, Seokyoun Kangb, Jeong Tai Kim
(Department of Architectural Engineering, Kyung Hee University

Another example of study in figure 9.9 aims to analyze the maximum electric energy production according to the inclination and direction of photovoltaic (PV) installations and the effects of the installation distance to the module length ratio. The annual solar insolation on PV panels was calculated for various building façade typologies, and an analysis of different horizontal and vertical inclinations of PV panels was also conducted in consideration of the effects of panel shading from other panels.

In additional, solar PVs can provide an excellent opportunity for aesthetic and environmental innovation. Panels can replace roofs, and wall cladding systems can cover existing unsightly concrete buildings, provide rain coverings and act as roof lights. However, there is also an economic and a cost issues that may or may not be able to afford the renewable technologies. Therefore, control and manage energy use should be an economically strategy, and in additional minimize cost for renewable technology.

9.3.4 Efficient computation and simulation process

The majority of energy assessments are based on the computation and simulation methodology. Their outcome provides a high significant of data for predicting and optimizing the building design and its energy performance The information gained from visualization and quantitative data needs to be further analyzed. There is a high tendency to obscure and manipulate data and graphics during the modeling and simulation process, which leads to unreliable outcomes. Below are key factors that must take into account on simulation and computation process;

a. *Accomplishment and Goal;* Goal and objective that need to be accomplished must be define at the beginning of procedure state. This goal will lead and define every single step of simulation, computation, and modeling strategies. It will able to define variables for inputting within the simulation.

b. *Modeling strategy;* Find the best solution to support modeling strategy. One goal can be achieve by multiple modeling strategies. Different purposes always define different strategies. To make model strategy will respond to project goal.

c. *Physic, Codes and simulation configuration;* To be able to adjust and modify energy simulation and other computations, one will need a good fundamental understanding of physics. This is a scientific experiment thus the integration of engineering and science terminologies must be understood. Most of the energy simulation relates to the environment codes and rating systems such as LEED, ASHRAE 90.1&55, and IECC.

d. *Read and fix errors;* Error messages always appear in cases of modeling discrepancies, thus it is important to translate and solve all error messages moving forward to prevent misleading results.

e. *Transition between different softwares;* Transferring models between multiple software, to conduct various studies, is the most challenging aspect of simulation. Model expectations and outcomes must be defined and clear at the very initial stage of simulation to avoid errors.

f. *Time consuming;* All simulations and computations take a long time, 5 – 48 hours depend on the complexity of analysis, which must plan wisely.

g. *Reliability;* Criteria and baselines must be set up to measure and criticize results to determine their reliability.

9.5 Research work flow and summary

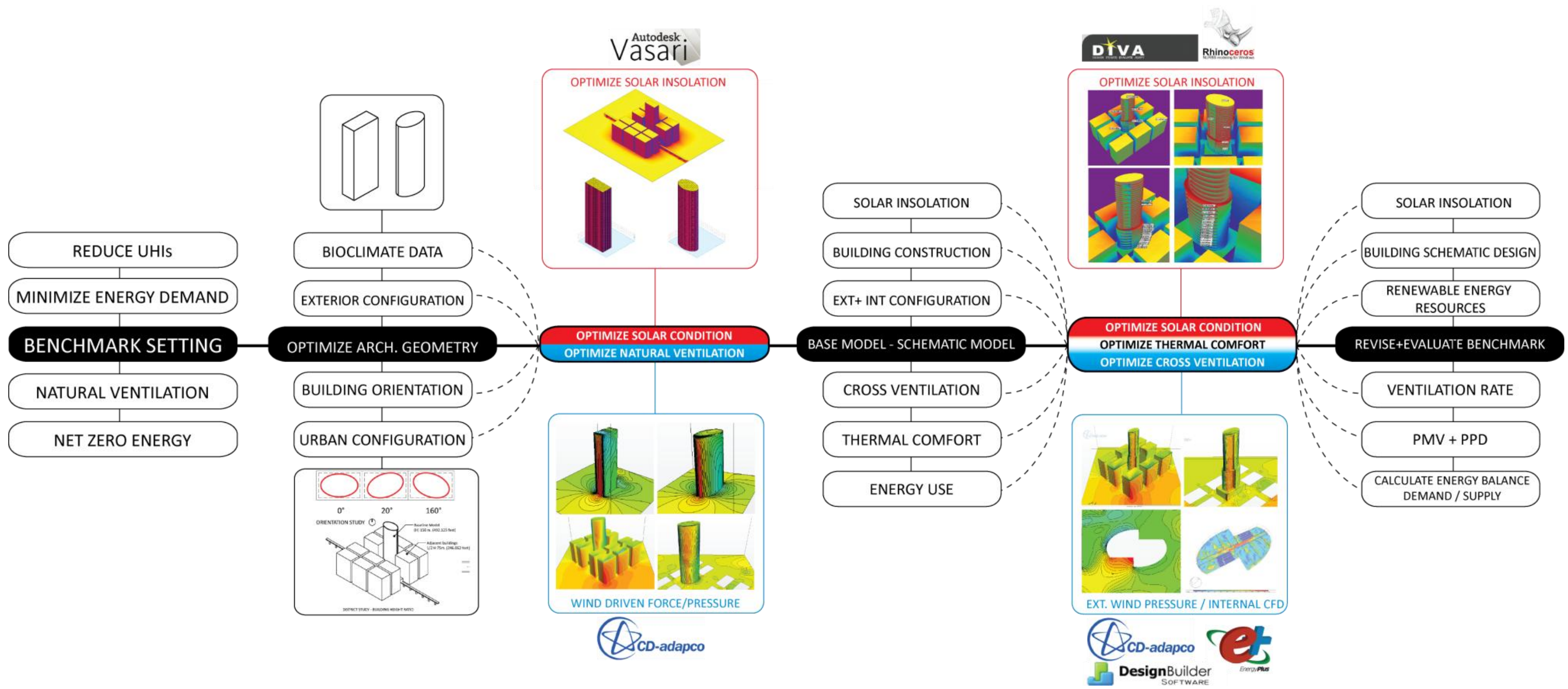


Figure 9.10: Research work flow summary diagram

9.4.1 Workflow summary

This work flow decribes a holistic perspective of reserch methodologies, which delivers all key significant factors from beginning of reserch step, implementation, and lastly evaluation. The greatest benefit of this frame work can be applied to any context to address a early stage of building design that maximize a passive cooling design and minimize energy consumption. Especially, computation fluid dynamic (CFD) and enrgy simulaton are taking another level of professional of arhitecture design meet to energineering value. Applying a building science into initial design process will bring opportunity of enhancing the sustainable design approach. Below are the workflow;

a. *Benchmark setting;* The first step is to define all project goals and accomplishments, which will guide the design strategies and intension for energy performance. Goals may include reduction of urban heat island, minimizing energy demands, optimizing a naural ventilation, and/or balancing energy demands with renewable energy supplies
b. *Optimize architectural geometry;* How can building geometry be optimized in terms of environment and energy? A baseline must be set to measure design approach. To analysis a general micro-climate condition within simply building geometries such rectilinear and oval shape for minimizing an exploded building surfaces to outdoor condition especially in extreme climate like Bangkok. Both solar irradiation and natural ventilation are major studies to provide a protential for reducing energy use. Both studies will provide a good baseline to optimize the building shape and orientation to ~~fit~~ within a particular context. Surrounded buildings and urban layout are all taken into consideration.
c. *Base model and schematic model;* After the conceptual building geometry is finalized, the effects of building construction on thermal tranmittance, and the effects of exterior geometry and interior layout on ventilation must be analyzed. Energy performance must also be simulated on the schematic design to explore any adjustments in configuration. In addition, critisize the energy use and whether or not it provides for internal thermal comfort.
d. *Revise and elevalute the energy benchmark;* the final stage of schematic design development consist of calculations and evaluations for the solar irradiation for potential solar energy and defining wind pressure differentials by measuring the amount

of pressure in both intake and exhaust will be needed to create the optimum ventilation. Also, compare amount of energy use from energy simulation with the predicted mean vote (PMV) and predicted percentage dissatified (PPD) to determine the internal thermal comfort that people will experience. In addition, calculate and compare on-site renewable energy sources from which the schematic building design can provide. Ultimately, compare the energy simulation performance outcome to the early benchmark setting and determine whether or not the benchmark can be accomplished.

9.4.2 Softwares summary

The following is a list of software that were used in this thesis with a breif description of each, as well as pros and cons from researcher's experience.

a. *Autodesk Vasari*[16]*;* is focused on conceptual building design using both geometric and parametric modeling. It supports performance-based design via integrated energy modeling and analysis features.

Pros: It is very handy interface as BIM (Revit). Both solar and wind study are powerful in visualization and uses a less time to simulate.

Cons: The analysis is very conceptual and is still operating in its beta version (which means it is still under expirimentationQuantitative analysis can not be used.

b. *Diva for Rhino*[17]*;* is a highly optimized daylighting and energy modeling plug-in for the Rhinoceros - NURBS modeler. DIVA-for-Rhino allows users to carry out a series of environmental performance evaluations of individual buildings and urban landscapes including RadiationMaps, Photorealistic Renderings, Climate-Based Daylighting Metrics, Annual and Individual Time Step Glare Analysis, LEED and CHPS Daylighting Compliance, and Single Thermal Zone Energy and Load Calculations.

Pros: Radiation Maps analysis is very powerful and reliable as well as other tools for analysis. Analysis toolkit is handy and convenient to use and set up.

Cons: There is a limited default SRI[18] materials which is a little complex to create. Some analysis may take a long time, such as Photorealistic Renderings and Radiation Maps, depending on complexity of the materials and the model.

c. *DesignBuilder*[19]*;* combines rapid building modeling and ease of use with state of the art dynamic energy simulation. DesignBuilder features an easy-to-use OpenGL solid

[16] http://labs.autodesk.com/utilities/vasari/
[17] http://diva4rhino.com/
[18] Lawrence Berkeley National Laboratory, 2001

modeller, which allows building models to be assembled by positioning, stretching and cutting 'blocks' in 3-D space. Realistic 3-D elements provide visual feedback of actual element thickness and room areas and volumes and there are no limitations on geometric form or surface shape. Data templates allow you to load common building constructions, activities, HVAC & lighting systems into your design by selecting from drop-down lists. You can also add your own templates if you often work on similar types of buildings. This, combined with data inheritance, allows global changes to be made at building, block or zone level. You can also control the level of detail in each building model allowing the tool to be used effectively at any stage of the design or evaluation process.

Pros: Modeling interface is very powerful, friendly and straight forward with construction and template examples. Energyplus is running as the background for the analysis, therefore, it is reliable. Provides the external and internal CFD function ~~to~~ for analysis and ventilation study.

Cons: Complex building geometry is not easily created or modified. CFD tool uses the uniform grid, which is an automatically adjust for us. CFD cannot handle a complex geometry or overlapped positions. CFD takes a long time to run simulation depending on size and detail.

d. CD-Adapco (Star-CCM+)[20]; provides the world's most comprehensive engineering simulation inside a single integrated package. Much more than just a CFD solver, STAR-CCM+ is an entire engineering process for solving problems involving flow (of fluids or solids), heat transfer and stress. STAR-CCM+ is unrivalled in its ability to tackle problems involving multi-physics and complex geometries. STAR-CCM+ has an established reputation for producing high-quality results in a single code with minimum user effort. Designed to fit easily within your existing engineering process, STAR-CCM+ helps you to entirely automate your simulation workflow and perform iterative design studies with minimal user interaction.

Pros: Maximize an advance potential CFD analysis. It is very powerful visualization and data output beyond other conventional CFD softwares. The simulation results are reliable with intensive analysis details.

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[19] http://www.designbuilder.co.uk
[20] http://www.cd-adapco.com

Cons: This is very advance engineer software built for engine parts, aerodynamic, and advance fluid or solid simulation; but not architecture. An independent workflow and modeling strategy needs to be created for an architectural analysis. The modeling interface is not as user friendly as the typical 3D software, but it allows for CAD import. Because it is engineering software terminology and information are very specific and must be thoroughly understood to avoid errors.

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